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Data Collection and Analysis of Moisture and Soil Strength Information for Validation of New State-of-the-Ground Models

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ABSTRACT: This report provides data from a weather station near Mound, LA, on a fluvial plain at a site entitled Mud Lake. Mud Lake is located across the Mississippi River, 10 miles from Vicksburg, MS. The weather station data were collected over a 1-year period. These data are reported real-time through telemetry to the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg. Data collection teams were sent to the site intermittently to collect soil moisture, soil strength, and other related soils data for calibration with the weather station probes and support of input requirements to FASSST-C.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
gallons	3.785412	cubic decimeters
horse-power	0.7457	kilowatts
inches	2.54	centimeters
miles (U.S. statute)	1.609	kilometers
pounds (mass)	0.4535924	kilograms
pounds/square inch	6.894757	kilopascals
pounds/square inch	0.071	kilograms/cm^2
pounds/cubic foot	0.016032859	grams/cm^3
short tons	0.907	metric tons
square feet	0.09290304	square meters
square inches	6.4516	square centimeters
square miles	2.589998	square kilometers
square yards	0.8361274	square meters
yards	0.9144	meters

Preface

The purpose of this report was to collect data to validate a high-resolution model for mapping moisture and respective soil strength changes. This information was collected in a fluvial plain in a temperate climate. The scope of this study was limited to data collection and calibration; therefore, no comparisons were made between field data and existing soil moisture-soil strength models.

Members of the staff of the U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), Engineering Systems and Materials Division (ESMD), Mobility Systems Branch (MSB), Vicksburg, MS, conducted the study reported herein. The work was conducted under the Work Item Code 007GAK "Base Camp Support." The project was funded through Cold Regions Research and Engineering Laboratory in an effort to verify and validate new high-resolution state-of-the-ground models. The work was conducted between January and October 2002.

The study was conducted under the general supervision of Dr. David W. Pittman, acting Director, GSL; Dr. Albert J. Bush III, Chief, ESMD; and Dr. David A. Horner, Chief, MSB. Dr. George L. Mason and Mr. Dennis W. Moore supervised data collection and conducted the overall analysis. Ms. Glenda M. Brandon supported data collection and analysis. Mr. David L. Leese, Instrumentation System Development Division, Information Technology Laboratory, ERDC, maintained the weather station and supported data collection.

Dr. Mason, Mr. Moore, Ms. Brandon, and Mr. Leese prepared the report.

COL James R. Rowan, EN, was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Soil strength and soil moisture provide the Army with insight into areas of mobility, cover and concealment, and target recognition. For mobility, increases in soil moisture reduce soil strength for fine-grained materials. This loss in soil strength allows the vehicle to sink, building up resistance to the vehicle's forward movement. Traction of a vehicle can be reduced by surface moisture. A combination of traction loss, motion resistance, and slope will affect mobility on most areas of the battlefield.

Soil moisture provides information related to other areas of the military. Infrared targeting systems use the thermal background signature related to moisture to acquire targets. Changes in soil moisture will change the thermal background of a ground target. Moisture fluctuations in the ground correlate to changes in ground temperature; thus, understanding the thermal signature of the ground supports detection of enemy vehicles, minefields, and personnel. Moisture changes are also related to changes in the shear modulus of the soil, which in turn, change the seismic properties of the soil. Ground sensors attached to smart mines or other listening devices are affected by physical changes in the ground.

A model was assembled in 2002 entitled FASSST–C, which contained algorithms to simulate snow, ice, temperature fluctuations, and moisture flow through the ground. FASSST–C includes a derivative of the Soil Moisture Soil Strength (Kennedy et al. 1988) and Short Term Operational Forecasts of Trafficability SOFT (Mason et al. 2001) models for prediction of the moisture content of soils based on weather. The FASSST–C also predicts soil strength. The model has had limited verification. The purpose of this report is to provide additional validation data to assess the accuracy of the FASSST–C model for moisture conditions in a temperate climatic regime.

This report provides data from a weather station near Mound, LA, on a fluvial plain at a site entitled Mud Lake. Mud Lake is located across the Mississippi River 16 km from Vicksburg, MS. The weather station data were collected over a 1-year period. The data are reported real-time through telemetry to the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg. Data collection teams were sent to the site intermittently to collect soil moisture, soil strength, and other related soils data for calibration with the weather station probes and support of input requirements to FASSST–C.

The supportive field data and algorithms used for data calibration and analysis are located in a "digital archives" folder on the CD-ROM included with the printed version of this report. A summary of the contents of each file along with the file path/name are provided in Table 1.

Table 1
Contents of Digital Archives

Path Name	Summary
/Digital Archives/Weather_Station/Spreadsheet/ curves.xls	This file contains relationships between soil plot of various coefficients for moisture and soil strength relationships
/Digital Archives/Weather_Station/Spreadsheet/ RCIOUT.xls	Soil strength output from Soil Moisture Soil Strength Prediction Model (SMSPII) and plots comparing results to the data from the weather station. This limited data set is not included in the discussions within this text but does provide insight into new coefficients required to relate moisture to soil strength
/Digital Archives/Weather_Station/Spreadsheet/ MUDLAKE2002G_eq.xls	Contains output from weather station along with computed soil strength. These data ran Dec 5, 2000 - Aug 5, 2002
/Digital Archives/Soils_Information/calibration.xls	Field data, probe data, and calibration curves
/Digital Archives/Soils_Information/ 2002curves.xls	Curves representing permeability relationships with moisture
/Digital Archives/Soils_Information/ dirt2002b.xls	Field data collected during testing to create calibration curves, cone index, density, moisture
/Digital Archives/Soils_Information/hydrometer.xls	Field data from the permeameter used to define some of the empirical equations in curves.xls

2 Background

Today potential sources of soil moisture data available to the tactical Army include point measurements by weather and agricultural stations, as well as data collected by Army tactical engineer technicians, archived climatological data, the Defense Satellite Meteorological Program (DMSP), and 3-hour soil moisture analyses available from the Air Force Weather Agency's (AFWA) agriculture meteorology model (AGRMET) (Gayno 2001). Data from all of these sources are of limited value to the Army for a variety of reasons. Measurements through weather stations or other field observers provide point data that do not necessarily reflect the conditions near the area of interest. The weather station measurements generally are difficult to obtain in hostile regions. Climatological statistics for the soil moisture for stations or grid points may be widely separated in space. These data, although useful for long-term planning, suffer from the fact that they represent and describe average values, which occur only rarely. The DMSP Special Sensor Microwave/Imager (SSM/I) soil moisture data have a validated resolution of 50 km (Hollinger et al. 1989). The SSM/I soil moisture retrievals can be useful in desert, or sparsely vegetated regions, and in heavily cultivated areas during the nongrowing season when the crop has been removed. These retrievals are less useful in moderate- to heavily-vegetated areas (e.g., moderate-to-heavy grass or forested areas). The SSM/I is only sensitive to soil moisture in the top 1 to 2 mm of soil, where the sensor has an unobstructed view of the soil.

Besides direct sensors, there are models designed to ingest sparse weather information and predict ground state. The AGRMET model is one such model. It is designed to predict moisture at the surface (0 to 10 cm) and three subsurface soil depths (30, 60, and 100 cm) with attributes of volumetric soil moisture data and snow for a 47-km gridded field every 3 hr. Figure 1 illustrates the output for soil moisture on the surface of the earth as provided by AFWA for an instance in time.

Moving to a higher resolution when describing the conditions of the terrain would support many of the models developed for mobility and target recognition. The ERDC developed the FASSST–C model to support this effort. As part of the validation effort, researchers at ERDC monitored a weather station at Vicksburg for 1 year. This report is restricted to defining the data, the collection methods, and providing the digital archives of that data to support the validation effort of FASSST–C. The report does not include FASSST–C model runs and comparison of the model output to data collected at the site.

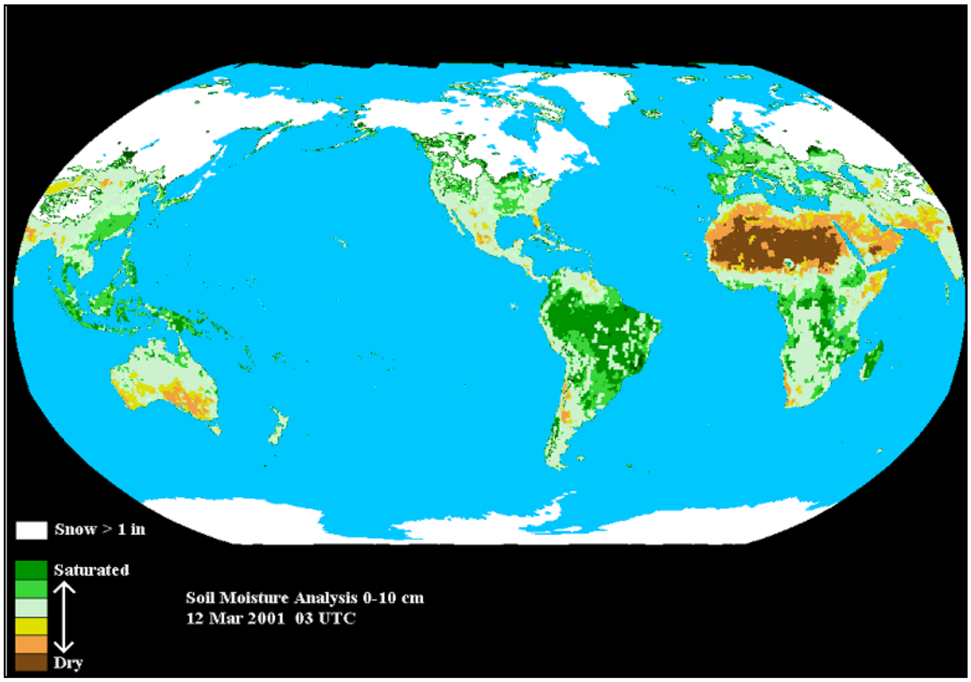


Figure 1. Soil moisture prediction for the surface of the earth (0- to 10-cm depth) from AFWA

Ideally, a method of defining moisture fluctuations at the ground level at extremely small spatial increments (<1 m) would support most engineering operations. Models are being designed to use this level of resolution, but data feeds would have to come from various sources. To validate these high-resolution, algorithms, a fully operational Class A weather station was established on a fluvial plain adjacent to the Mississippi River near Vicksburg. This study reports information from that site which would support a high-resolution fielded model.

3 Weather Station

The weather station was located on a fluvial plain near the Mississippi River located 8 km north of Mound, as shown in Figure 2. A Global Positioning System (GPS) defined the latitude and longitude as North 32 deg 24 min 43.5 sec and West 91 deg 01 min 25.2 sec with an elevation of 27 m above sea level. The site is on a flat plain with tilled crops of soybean and corn located nearby. A shallow drainage ditch 1 to 2 m deep was located 5 m from the site. The ditch stayed dry except in heavy rains. Flooding would occur in and around the site at these times preventing field data collection. The water table was estimated at a depth of 10 m.

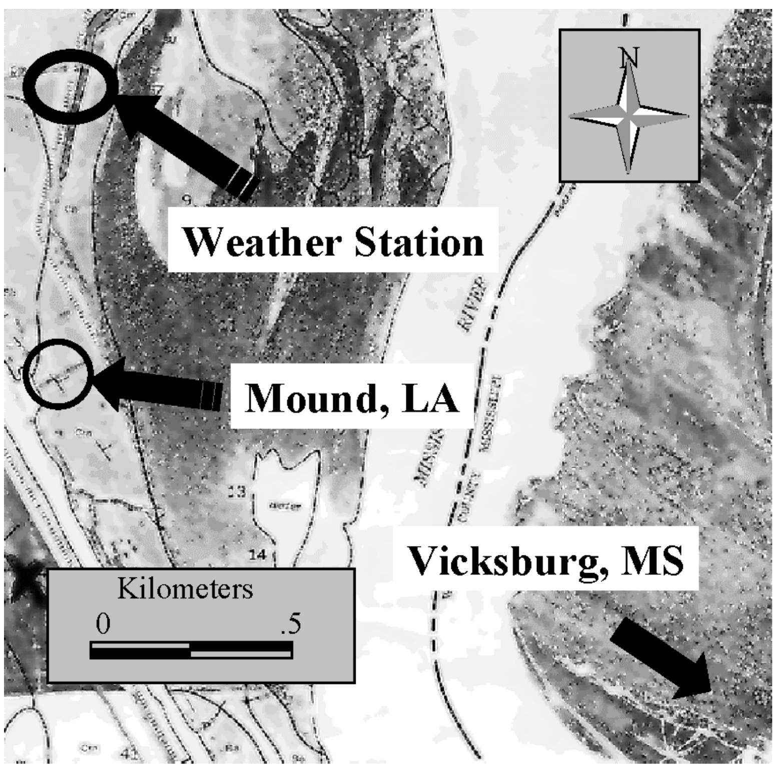


Figure 2. Site map of the weather station

Specifications for the weather station are provided in Appendix A. A photo of the site is shown in Figure 3. The weather station was configured with instrumentation to measure rain, wind, humidity, temperature, and evaporation. A cell phone was connected to the weather station in February 2001. The data collection unit inside the weather station collected information every 15 min and used the cell phone to download the information locally every 24 hr. Prior to this time, data were downloaded from the Campbell's data collection unit at the site using a portable computer. However, all probes, to include the evaporation pan (seen in Figure 3 behind the weather station), were not fully operational until March 2002.

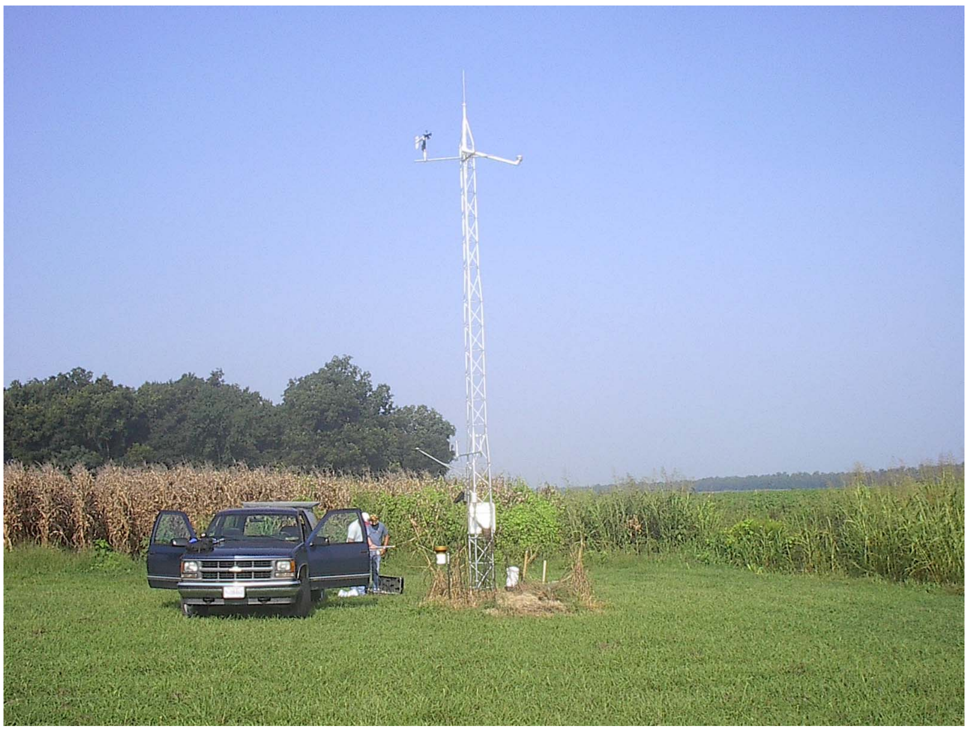


Figure 3. Weather station

Probes were placed in the ground adjacent to the weather station for defining temperature and moisture. The soil moisture and temperature probes were placed at depths of 2.5, 15.15, and 30.5 cm. The wind sensors were placed at 10 and 3 m above the ground. Figure 4 illustrates the soil moisture and temperature probes. The moisture probes had two rods, which were inserted horizontally to the ground surface. The temperature probes were emplaced in the same way. To place the probes in the ground, a trench was dug 40 by 50 cm in width and length, respectively. The probes were inserted parallel to the ground surface at each depth. The hole was then backfilled and tamped. Measurements did not start until after a period of 60 days to provide time for the probes to settle in the ground and allow for the backfilled areas to achieve a consistency similar to the in situ ground.

A table giving detailed soil properties is presented in Appendix B, and plates showing a comparison of measured field moisture are presented in Appendix C.

Figure 4.   Probe placement

The solar sensor was a LiCor Model LI200X pyranometer with a silicon Photovoltaic detector and the following attributes. Light spectrum waveband of 400 to 1,100 nm with a typical accuracy of ±3 percent, installed height of 2.5 m, units of watts per square meter (W/m^2). The solar sensor failed twice during the weather station operation: August 7, 2001, dropouts were observed from data collected; between March 3 – March 8, 2002, readings maxed out at 700 W/m^2. The solar sensor was replaced thereafter and data collection continued without incident. A spreadsheet entitled "MUDLAKE2002G_eq.xls" which contains recordings for this period is included on the CD. Column J of the file includes the raw data from the solar cell. Column N includes filtered data using a computerized routine that detects when these dropouts and max readings occur and corrects the data based on past observations, and column O has the raw data with –6,999 in cells, defining bad readings. Appendix D provides plots of the measured solar radiation.

4 Field Data Collection

The Class A weather station was initially set up and became operational in December 5, 2000, and operated continuously through January 21, 2003. In January 2002, a field data collection program was initiated to calibrate and compare the moisture probe data and the moisture strength relationships for the soils at the weather station. There were short periods of time during 2002 when data collection was stopped at the weather station including maintenance between October 5 and October 17, 2001. Battery failure occurred between April 17 and April 25, 2002. Between May 26 and June 15, a lightning storm damaged the weather station. Failure of the weather station to record in individual days of July 25 and October 21, 2002, was also recorded. Flooding occurred during the testing, preventing access to the site for a 3-week period and subsequent field data collection.

All field data were collected within 5 m of the weather station. Bulk soil samples were taken to determine the classification of the soil at the weather station. The soil was classified according to the Unified Soil Classification System (USCS) as a low plasticity silt (ML). However, the soil tests also showed that the soil was a border line between an ML and a CL (low plasticity clay). Soil strength measurements, using a cone penetrometer, were taken in the general area of the weather station. The cone penetrometer consisted of a 30-degree cone with a 0.5- or 0.2-in. square base area mounted on one end of a shaft. The shaft has circumferential bands to indicate depths of penetration. At the top of the shaft is mounted a dial indicator within a proving ring which indicates the force applied axially to the penetrometer. The instrument is forced vertically into the soil while records are made of the dial reading at various penetration depths.

As shown in Figure 5, field permeameter readings were made to determine the hydraulic field permeability and matrix flux potential. An example of a set of permeameter readings near the weather station is illustrated in Table 2.

Permeameter data were used to compute the saturated hydraulic field permeability, matrix flux potential, and the alpha coefficient useful in determining moisture changes with precipitation. The spreadsheet entitled "hydrometer.xls" included on the CD-ROM provides the raw data. Table 3 shows the maximum and minimum values measured in the field. Appendix E summarizes the data collected from the permeameter. Some of the measurements from the permeameter were negative. These data resulted from a high water table causing positive pressures in the soil. The negative permeameter measurements were not considered for inputs in the moisture model.

Figure 5. Placement of the field permeameter

Table 2
Field-Measured Permeability Readings

Depth of Sample	Field Saturated Permeability, cm/sec
0–15.15 cm	0.000261
15.15–30.5 cm	0.001070

Table 3
Standard Error Related to Field-Measured Permeability Readings

Depth of Sample	Field Saturated Permeability, cm/sec	
	Max	Min
0–15.15 cm	0.000193	0.000330
15.15–30.5 cm	0.002030	0.000118

In addition to permeameter readings, tension meters were placed at the site to collect soil tension data related to moisture content of the soil under ambient conditions. However, during very dry periods, the tension meters (Figure 6) required refilling of water and checking on a semi-daily basis which was not possible because of the remote location of the site. Therefore soil tension-moisture content data from this source were limited.

While the model FASSST–C can take inputs of a layered media for verification of the model, an average value is sometimes desired. The average permeability reading from Table 2 is 0.000667 cm/sec.

Figure 6. A field tension meter placed next to the evaporation tank

5 Calibration of Soil Moisture Probes

The moisture probes provide real time continuous readings at three depths 2.5, 15.15, and 30.5 cm. However, the probes are sensitive to various changes in soil properties. Swelling of the soil (Terzaghi and Peck 1948) can occur as a function of pressure, temperature, and/or water content. The soils at the Mud Lake site had over 20 percent passing the 0.001 mm sieve. The plastic limit of 26 and liquid limit of 40 indicate the soil has a low swelling potential (Holtz and Kovacs 1981).

All moisture probes are site specific and calibration constants have to be determined for each site so that accurate readings can be based on a reasonable number of field measurements. Campbell's scientific moisture probes (#615) were used in this study. These probes consist of two 30 cm stainless steel rods inserted into the soil. A deviation of the return from a transmitted signal is measured, based on the dielectric properties of the soil, which are determined, in part, by water content. Accuracy, as quoted by the manufacturer is in the range of ±2 percent when using calibration for specific soil types. The study reported herein used measured gravimetric moisture data and density to verify the algorithms for calibration.

Soil samples for determining moisture content by oven drying were taken in and around each area to establish a correlation for the probes. These samples were taken at the same depths and within a 50-yard radius of the weather station.

Figure 7 illustrates a plot of measured (2.5-cm depth) probe values (x axis) versus measured gravimetric moisture data (y axis). The R^2 value of 0.8205 suggests a good correlation between the probe data and field-measured soil moisture data. The field data in the figure have been assigned error bars in the y axis, based on an expected 10 percent probability of error as suggested by Harr (1987). In general, the probe data taken at a depth of 2.5 cm compares well with the measured field values.

Figure 8 is a comparison of the 15.15-cm-deep moisture probe data (x axis) and measured gravimetric (or moisture content by weight) field data (y axis). The gravimetric moisture content is the weight of water as compared to the weight of dry material. The R^2 correlation between the data is 0.4598. The

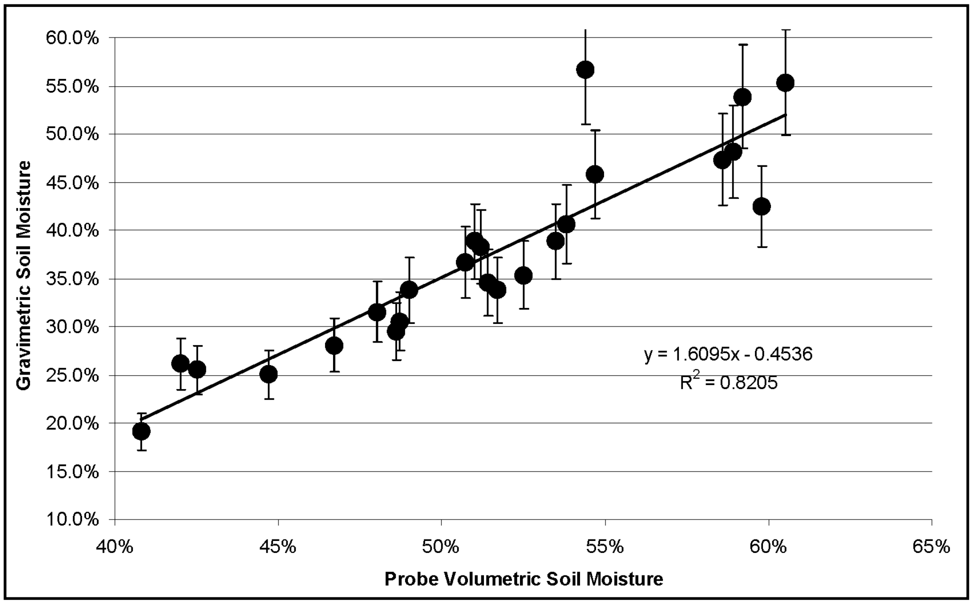


Figure 7. Comparison of probe data versus measured moisture at 2.5-cm depth

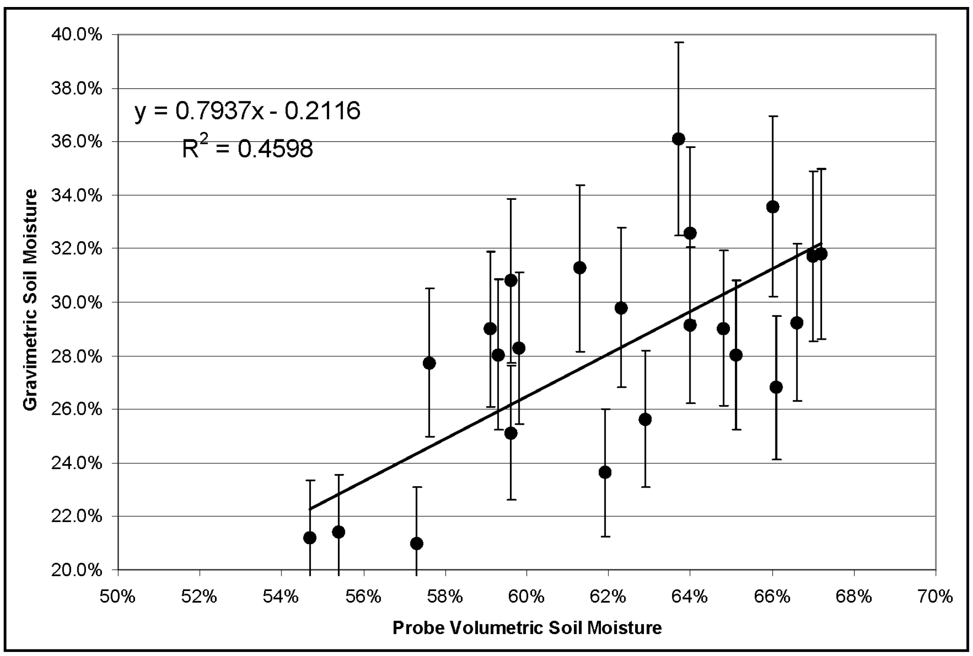


Figure 8. Comparison of probe data and measured data at 15.15-cm depth

probe readings near the surface generally show wider variations than at the subsurface. The probe values at 15.15 cm varied from 60 to 68 percent (8-percent range), while the probe values at 2.5 cm ranged from 40 to 60 percent (20-percent range).

Figure 9 is a comparison of the volumetric moisture content as measured by the field probe (x-axis) to the gravimetric moisture content data (y axis). Figure 9 shows the measured probe data from the weather station and field data at 30.5 cm.

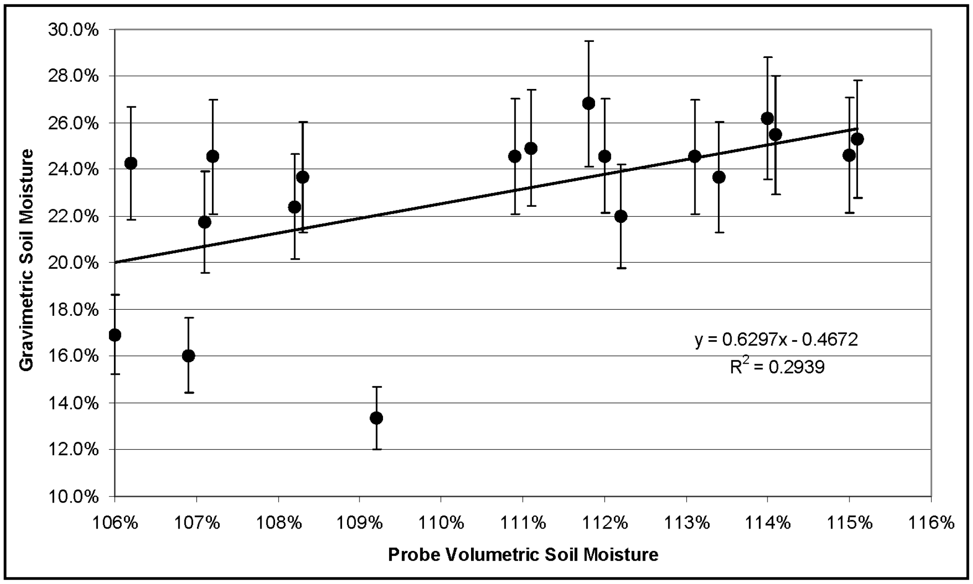


Figure 9. Comparison of probe data and measured data at 30.5-cm depth

Figure 9 has a relatively poor correlation between data of $R^2 = 0.2939$. Three outliers in Figure 9 are identified that when removed would support a better correlation between volumetric and gravimetric measurements. These low readings appear to be in error from field measurements, possibly because of incorrect readings of weight or problems in collection of sample. Possible reasons for the poor correlation include the limited variation moisture (0.13 - 0.24 percent) at the 30.5-cm depth. Also note in Figure 9 that the probe data for volumetric moisture exceed 100 percent. This is in part because the coefficients used initially to define volumetric moisture of the probes were for a different soil as established by the manufacturer.

Figures 7, 8, and 9 show the relationship between volumetric data as defined by the output of the probe in the field and field-measured volumetric data computed from the oven-dried samples taken in the field. When using field-measured dry density, the gravimetric field data can be converted to volumetric field data using Equation 1.

$$\omega_v = \frac{\gamma_d}{\gamma_w} * \omega_g \tag{1}$$

where

ω_v = volumetric moisture

γ_d = dry density

γ_w = density of water

ω_g = gravimetric moisture

The volumetric field data were used to calibrate the volumetric probe data. The correlation coefficients determined between measured volumetric and gravimetric (weight) field data and the probe data are summarized in Table 4. These data are further defined in the spreadsheet entitled "calibration.xls." The coefficients are provided in the form of Y = AX + B where Y is the field data and X is the measured probe data.

Table 4
Predicted Coefficients Derived from Measured Probe and Field Data

Depth (cm)	Probe vs. MC					
	Weight			Volume		
	R^2	A	B	R^2	A	B
2.5	0.821	1.610	-0.454	0.863	2.184	-0.619
15.15	0.460	0.794	-0.212	0.490	1.239	-0.345

The average, maximum, and minimum values at each depth are depicted in Figure 10 over the 4-month period (February 2002 and May 2002). Total variations in moisture readings were different for each depth. The surface layer had deviations of 60 percent. The 15.15-cm depth varied 25 percent. The 30.5-cm layer varied slightly less than 20 percent. The average moisture content of the surface layer was 39 percent; the subsurface layers both had averages of 28 percent moisture content.

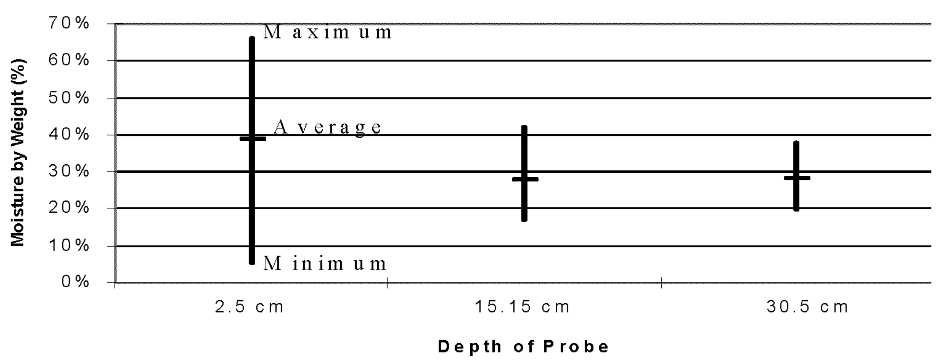


Figure 10. Changes in moisture over entire testing period for each depth

At the 30.5-cm depth, the probe operated from 12/05/00 to 11/27/01. The probe failed on 11/27/01 and was replaced 04/16/02. The maximum and minimum values recorded by the probe during its first operation were 0.891 and 0.602, respectively. The second moisture probe operated for 4 months between 04/16/02 and 01/20/03, and the data recorded ranged from 1.187 to 1.033. Table 5 illustrates the coefficients used for the respective time periods relating the probe measurements to the volumetric and gravimetric field measurements. Figure 11 illustrates the offset induced when the new probe was introduced at the 30.5-cm depth. A calculated coefficient of 0.4 was added because of the offset introduced when the new sensor was added.

Table 5
Predicted Coefficients (30.5-cm depth) from Measured Probe

Date		Probe vs. Measured Moisture Content 30.5-cm depth					
		Weight			Volume		
Start	End	R^2	A	B	R^2	A	B
12/05/00	11/27/01	--	0.6297	-0.2160	--	2.7496	-1.447
03/5/02	08/05/02	0.294	0.6297	-0.4672	0.294	2.7496	-2.5448

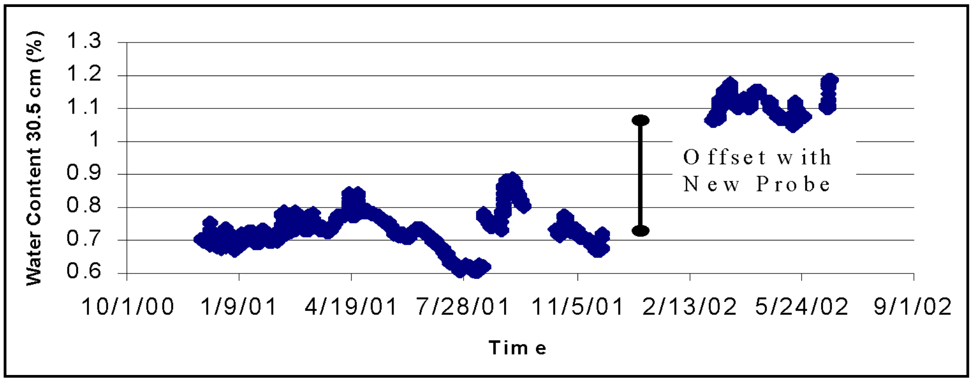
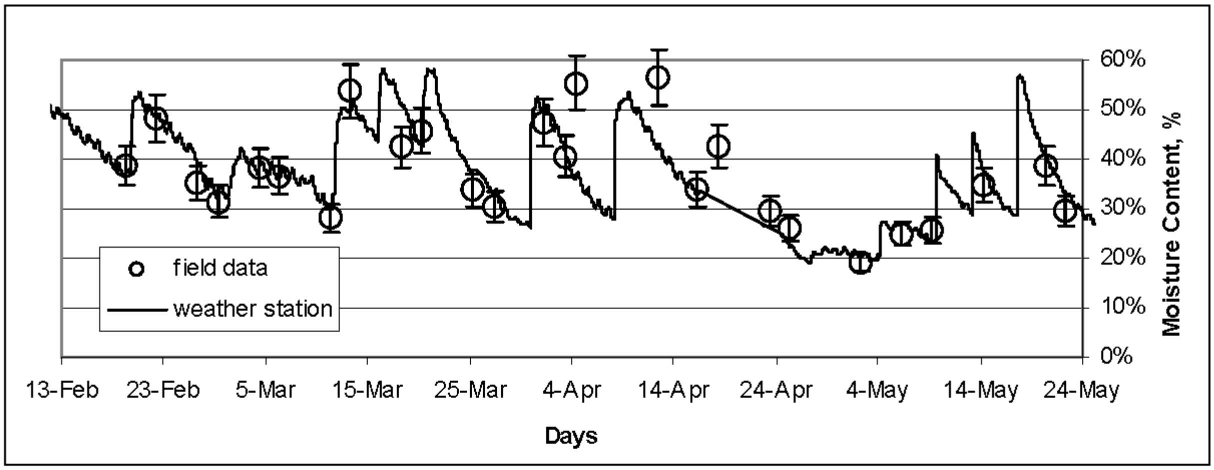
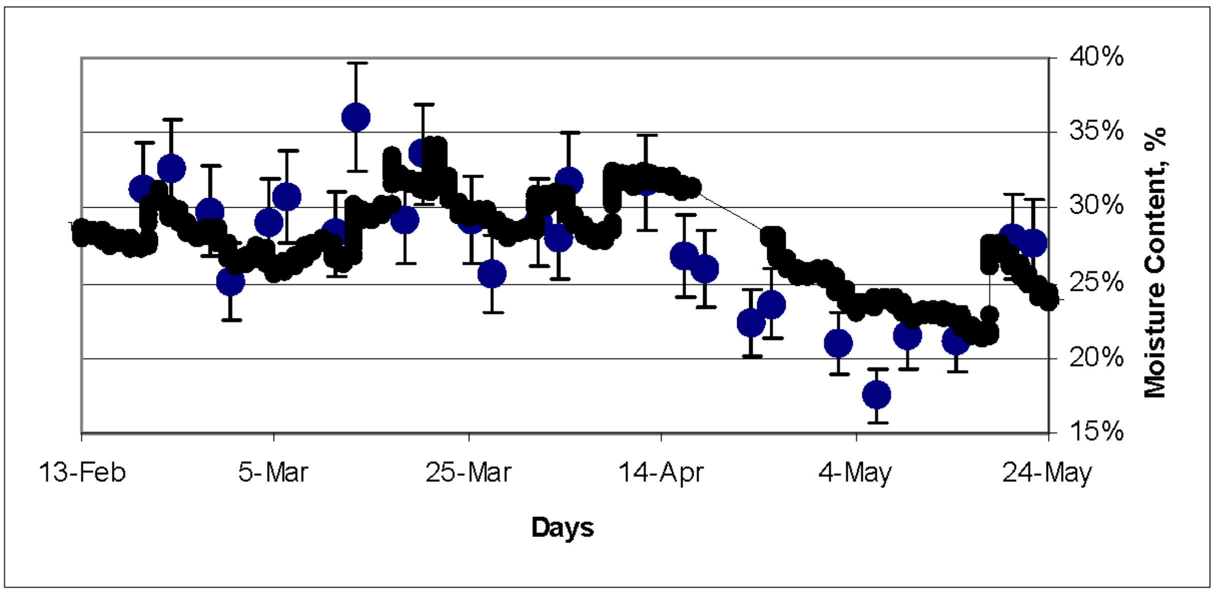


Figure 11. Offset resulting from insertion of new probe

A composite plot of the surface measurements with corrections and the probe measurements over the period of monitoring is depicted in Figure 12a and 12b. The bars on the data points depict the expected error associated with the laboratory tests and field collection, as stated by Harr (1987). While the samples were taken as close as possible to the probe, spatial variability could have introduced some additional error in the plot.



a. Near the surface (2.5 cm)



b. At 15.15 cm depth

Figure 12. Comparison of measured probe data and measured field data

6 Calibration of Soil Properties

Field Measurements of Soil Properties

Figure 13 illustrates the typical range of field measured soil strength (RCI) values when a soil profile is made at a location. In Figure 13, a box plot is used to define the maximum, minimum, and lower decile reading of 10 punches of the cone penetrometer. This soil strength profile is highly correlated to the depth of the measurement, the soil type, and the soil moisture. Soil moisture and density were collected at the weather station during various time periods depending on the weather. While these weather station measurements were available over a 2-year period (2000 – 2002), the soil profiles provided in this report were focused between January and August 2002, when field data were collected almost daily adjacent to the weather station.

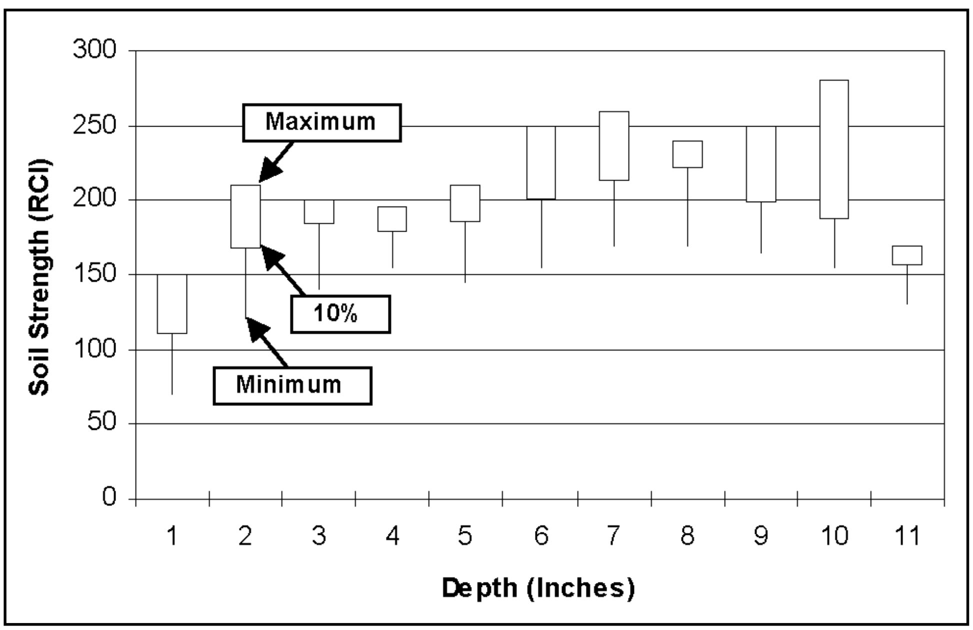


Figure 13. Plot of soil strength versus depth on 2/19/2002

Table 6 illustrates the collected data and computations for the field density and moisture content measurements. A Hvorslev Sampler was used to extract the 0- to 6-in. (0- to 15-cm) and the 6- to 12-in. (15- to 30-cm) samples. The surface (SFC) soil samples were collected from the top 2 cm of soil. The loose nature of the surface soil prevented accurate dry density measurements. The samples were oven dried and the densities were calculated for the 0- to 6-in. (0- to 15-cm) and 6- to 12-in. (15- to 30-cm) layers.

Table 6
Moisture/Density Data for the Weather Station (2/19/2002)

	TIME	**9:15**	
DATE	**2/19/2002**	**SITE**	**#1**
Depth	SFC	0 – 6	6 – 12
Can No.	830K	1049C	1122C
Wet & Can (grams)	172.6	367.4	387.7
Dry & Can (grams)	152.7	303.7	326.8
Water (grams)	19.9	63.7	60.9
Can (grams)	101.5	100	100
Dry Soil (grams)	51.2	203.7	226.8
% Moist.	38.9%	31.3%	26.9%
Dry Density (lb/ft^3)		81.5	90.7

Void ratio is computed from these values using Equation 2. A summary of the field-measured void ratio, moisture content, and dry densities is given in Table B1. The average void ratio measured at the site was 0.976 for the 0- to 15-cm level, and 0.783 for the 15- to 30-cm level. The standard deviation of these data was 9 and 4 percent, respectively. The drop in void ratio between the surface and the subsurface readings was consistent, as expected, for all measurements, verifying increased consolidation with depth of the soil.

$$e = G_s * \frac{\gamma_w}{\gamma_d} - 1 \quad (2)$$

where

e = void ratio, percent

G_s = specific gravity

γ_w = unit weight of water, pcf

γ_d = unit weight of soil or dry density, pcf

Figure 14 illustrates changes in dry density for the surface and subsurface measurements. These changes may be attributed to sample error or swelling of the clay. The average dry density measurements for the 0- to 15-cm layer between February and July were recorded as 85.1 lb/ft^3 with a standard deviation of 3.7 lb/ft^3. The 15- to 30-cm layer dry density was recorded as 94.3 lb/ft^3 with a standard deviation of 1.5 lb/ft^3. These data included 29 measurements made

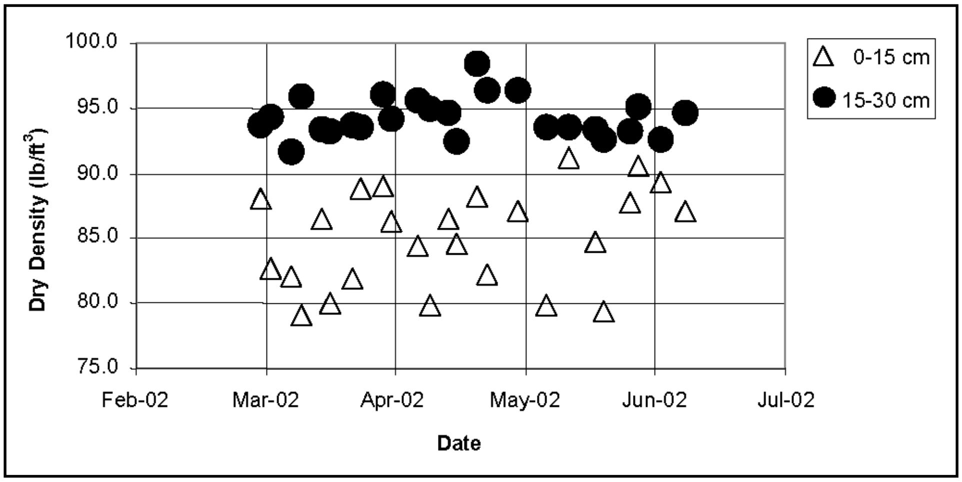


Figure 14. Dry density versus time for the weather station

during the 6-month period. Dry density of a soil at a specific site will fluctuate with moisture content depending on the swell potential of the material. At this site, the average moisture content near the surface was 36.8 percent over the same period of time with a deviation of 10 percent. The 0- to 15-cm layer over the February through July period exhibited average moisture content of 26.7 percent with a 4.4 percent deviation. The 15- to 30-cm layer had 22.4 percent average gravimetric moisture content with a 3.5-percent deviation. As expected, the deviation in moisture content dropped with the deviation in density.

Correlations of Soil Moisture to Soil Strength

Gradations, hydrometer analysis, specific gravity tests, and Atterberg Limits were conducted on the soil from the site. The laboratory analysis is provided in Appendix B. Moisture contents at the plastic and liquid limits are 26 and 40 percent, respectively. Cone index readings correspond to moisture contents near the Atterberg Limits, i.e., low cone index readings will occur near the liquid limit; high cone index readings will occur near the plastic limit. Moisture content versus average cone index readings for the surface, 0- to 15-cm, and 15- to 30-cm layers are illustrated in Figure 15.

The coefficients derived from this measured set of data points are given in Table 7. These values were compared against those published in SMSP II (Sullivan et al. 1997) for similar soil types (ML & CL). The coefficients from the SMSP II report did not appear to follow the trend of the data at the site. This may have been due to difference in the density of the soil at the site as compared to the measured density of the soil in the SMSP II report, as indicated in Table 7. Dashed lines are shown in the plot indicating the error bounds of the equation. This assumes an expected variance in the predicted data of 10 percent. The surface and subsurface readings were grouped together because they independently did not appear to form separate lines. The coefficient of variation was

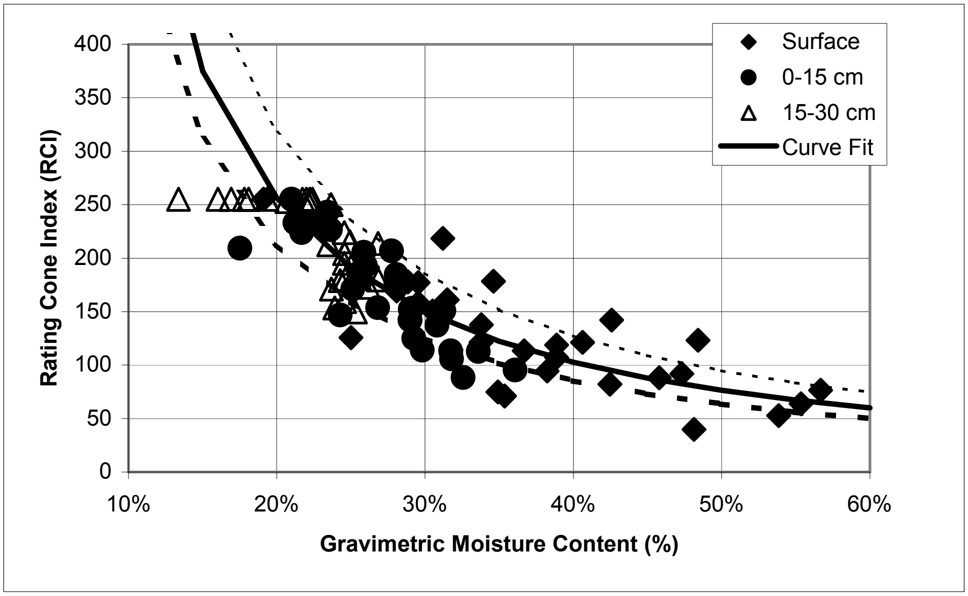


Figure 15. Field soil strength versus moisture content

determined as 0.6158, indicating a relatively good fit of the data to the curve fit line. Equation 3 defines the general empirical relationship between moisture and soil strength.

$$\begin{aligned} RCI &= \exp\{9.5055 - 1.3216[\ln(\omega\% * 100)]\} \\ RCI &= \exp[\alpha + \beta * (\ln \omega)] \end{aligned} \qquad (3)$$

where ω is the moisture content.

Note in Table 7 densities at the weather station (Mud Lake) were higher than those average values provided as default in SMSP for similar ML soil types.

Table 7
Computed Average SMSP Relationships Versus RCI

Soil Type USCS	Density (lb/ft^3), γ_d	Soil Strength Coefficient, α	Soil Strength Coefficient, β
Mud Lake (ML)	85.1	9.5055	-1.3216
CL	86.8	15.506	-3.5300
ML	73.7	11.936	-2.4070
CL-ML	83.7	14.236	-3.1370

7 Static Parameters for FASSST–C

The purpose of this chapter is to define input/output parameters for FASSST–C code in an effort to establish a basis field data which will in turn support validation efforts of the model. Table 8 lists soil parameters required for model initialization. The required static input data for prediction of soil moisture is:

a. Site Latitude (North,): N 32 deg 24 min 43.5 sec.

b. Site Longitude (West from Zulu): W 91 deg 01 min 25.2 sec.

c. Site Elevation (m, ft): 27.432 m.

d. Slope (Degrees from Horizontal): 0 percent, 0 deg Accuracy ±1 percent.

Table 8
Input Parameters for Initiating FASSST–C

FASSST–C Parameters	Default Parameters	Mud Lake Parameters	Coefficient of Variation
Dry Density γ_d (g/cm^3)	1.457	1.3644	4%
Void Ratio (%)		0.976	9%
Albedo	0.40		
Emissivity	0.94		
Quartz content	0.35		
Saturated field Permeability (cm/sec)	0.0001231	0.000667	See Table 4
Residual Moisture (%)	0.01	0.08[1]	0.02[1]
Maximum Moisture (%)	0.464	0.39[2]	0.10[2]
Sorbivity (cm/sec^5)	0.57		
Van Genuchten exponent	1.5		
Cone Index Coefficient 1	10.225		
Cone Index Coefficient 2	-1.565		
Rating Cone Coefficient 1	11.936	9.5055	
Rating Cone Coefficient 2	-2.407	-1.3216	
Soil Matrix Flux Potential (cm^2/sec)		0.0392	See Table 4

1 Based on the lowest observed moisture content.
2 Computed from specific gravity, void ratio, 100-percent saturation and average moisture content using the equation below:

$$w = \frac{G}{e}$$

where

w = average gravimetric moisture, percent
G = specific gravity
e = void ratio, percent

8 Conclusions and Recommendations

Conclusions

Although moisture probes provide invaluable information for validation of water budget models, the probes must be calibrated with field measured data to ensure accurate results.

This study indicates that the soil strength coefficients used in FASSST–C values did not appear to follow the correlations between moisture content and moisture strength for ML soils, as defined in prior studies by Sullivan et al. (1997). The Mud Lake site had higher soil densities than those used as default values for ML soils.

Moistures at deeper depths varied less than those at the surface. Default values defining correlations between soil strength and moisture content had to be modified to support findings in test area. This also included density and permeability readings.

Recommendations

Based on results of this study, it is recommended that:

a. Site monitoring stations be expanded to other areas with different soil types.

b. Site monitoring stations be expanded to other climatic regions.

c. Use of existing commercial and government weather stations in other regions for validation of FASSST–C relationships should be considered.

d. Plastic and liquid limits need to be incorporated within the FASSST–C model to establish bounds on moisture content and soil strengths.

e. Automated means for collection of soil strength should be considered.

f. Evaporation pans are critical to this type of validation effort. More evaporation pans should be placed at the site for redundancy.

g. Because of travel times, field weather stations should be located within 96 km of the laboratories. This is particularly true for areas where extensive field data must be collected.

h. Moisture probes need to be calibrated at each site.

i. Tension meters should be automated so field time is minimized.

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Appendix A Specifications for Mud Lake Weather Station

Meteorological data collected at the Mud Lake, Louisiana, site engage the following sensors:

Air temperature at 10 m: Air temperature is monitored using the Campbell Scientific probe Model 107.

Model 107 thermistor installed in a gill-type radiation shield. This sensor has a range of –35 to +50 °C with a typical accuracy of less than ±0.1 °C.

Air Temperature at 2 m: This parameter is measured using a Vaisal Model HMP45C.

Temperature and relative humidity probe. Accuracy for the temperature probe is ±0.2 °C from –40 to +60 °C. Installation height is 2 m. Units are °C.

Relative Humidity: This parameter is monitored using the above referenced Vaisala.

HMP45C. Accuracy for this sensor is ±2 percent RH (0 to 90 percent Relative Humidity) and ±3 percent (90 to 100 percent Relative Humidity). Installation height is 2 m.

Barometric Pressure: This parameter utilizes a Vaisala Model PTB101B Pressure.

Transmitter. Total accuracy is ±6 mBars at –40 °C to +60 °C. Installation height is approximately 1.75 m. Units are milliBars.

Solar Radiation: This sensor is a LiCor Model LI200X pyranometer with a silicon gage.

Photovoltaic detector. Light spectrum waveband is 400 to 1,100 µm with a typical accuracy of ±3 percent. Installed height is 2.5 m. Units are Watts per square meter (W/m^2).

Wind Speed: R.M. Young is the supplier for the wind speed/direction sensor package.

Model Number is 05103-5. The wind speed accuracy is ±0.3 m/s (0.6 mph) and has a range of 0 to 100 m/s (up to 220 mph). Threshold sensitivity is 1.0 m/s. Installed height is approximately 9 m. Units are meters per second.

Wind Direction: Utilizing the RM Young model 05103-5 wind direction sensor.

Monitored with an accuracy of ±5 deg. Installed height is approximately 9.0 m. Units are in Degrees from North.

Wind Direction: Wind direction data at the 3 m level is collected using a Met One model.

024A. Threshold for this sensor is 0.5 m/s with an accuracy of ±5 deg. Units are in Degrees from North.

Wind Speed: Wind speed at the 3 m level is monitored with a Met One model 014A Wind

Speed Sensor: Specifications include a startup threshold of 0.45 m/s, a range of 0-45 m/s and an accuracy of 1.5 percent or 0.11 m/s.

Precipitation: The precipitation sensor is a Texas Electronics Model TE525MM: Calibrated for millimeter output. Accuracy for rainfall rates is as follows:

Up to 10 mm/hr, ±1 percent
10 to 20 mm/hr, +0, -3 percent
20 to 30 mm/hr, +0, -5 percent
Units are millimeters.

Soil temperature: Soil temperatures are monitored using a Campbell Scientific Model 107B epoxy thermistor bead. This sensor has a range of –35 to +50 °C with a typical accuracy of less than ±0.1 °C.

Soil moisture: The CS 615 probe excites and measures two 30.0-cm stainless rods.

Deviation of return from transmitted signal is dependent on the dielectric properties of the soil, which is correlated to water content. Volumetric water content is determined after applying an algorithm that is soil type specific. Accuracy is in the range of ±2 percent when using calibration for specific soil type.

Appendix B
Soil Properties

Table B1
Measured Field Soil Properties

							Specific Gravity 2.69
Weather Station Data				**Dry Density lb/ft^2**		**Void Ratio Percent**	
	Moisture Content, % Dry Weight						
Date	**Surface**	**0 – 6**	**6 – 12**	**0 – 6**	**6 – 12**	**0 – 6**	**6 – 12**
	38.9	31.3	26.9	81.48	90.72	1.060	0.850
02/21/02	48.1	32.6	23.9	84.28	95.00	0.992	0.767
02/26/02	35.4	29.8	25.6	85.36	92.92	0.966	0.806
02/28/02	31.5	25.1	25.4	89.16	95.44	0.883	0.759
03/04/02	38.2	29.0	25.4	88.00	93.64	0.907	0.793
03/06/02	36.7	30.8	24.3	82.72	94.28	1.029	0.780
03/11/02	28.1	28.3	24.6	82.12	91.72	1.044	0.830
03/13/02	53.8	36.1	24.6	79.16	95.88	1.120	0.751
03/18/02	42.5	29.2	25.5	86.44	93.36	0.942	0.798
03/20/02	45.8	33.6	26.2	80.04	93.20	1.097	0.801
03/25/02	33.8	29.1	26.8	81.96	93.64	1.048	0.793
03/27/02	30.5	25.6	24.9	88.76	93.56	0.891	0.794
04/01/02	47.3	29.0	24.6	89.04	96.00	0.885	0.749
04/03/02	40.6	28.0	24.6	86.36	94.16	0.944	0.783
04/09/02	55.4	31.8	23.7	84.40	95.56	0.989	0.757
04/12/02	56.7	31.7	24.6	79.80	95.04	1.103	0.766
04/16/02	33.8	26.8	25.3	86.40	94.72	0.943	0.772
04/18/02	42.6	26.0	23.5	84.64	92.44	0.983	0.816
04/23/02	29.5	22.4	22.2	88.16	98.40	0.904	0.706
04/25/02	26.1	23.6	22.0	82.28	96.36	1.040	0.742
05/02/02	19.1	21.0	22.4	87.04	96.36	0.928	0.742
05/06/02	25.0	17.5	21.7	N/A	N/A	N/A	N/A
05/09/02	25.5	21.4	16.0	79.92	93.52	1.100	0.795
05/14/02	34.6	21.2	16.9	91.24	93.56	0.840	0.794
05/20/02	38.9	28.0	13.4	84.72	93.36	0.981	0.798
05/22/02	29.5	27.7	23.7	79.44	92.60	1.113	0.813
05/28/02	31.2	23.4	17.8	87.80	93.24	0.912	0.800
05/30/02	48.4	25.9	18.1	90.64	95.16	0.852	0.764
06/04/02	28.9	21.7	19.3	89.28	92.64	0.880	0.812
06/10/02	34.9	24.3	20.7	87.16	94.64	0.926	0.774
Average	37.0	27.1	22.8	85.1	94.2	0.976	0.783
Standard Error				3.61	1.61	0.084	0.030
% Variance				4%	2%	9%	4%
Note: A table for converting non-SI units of measurement to SI units is presented on page vi.							

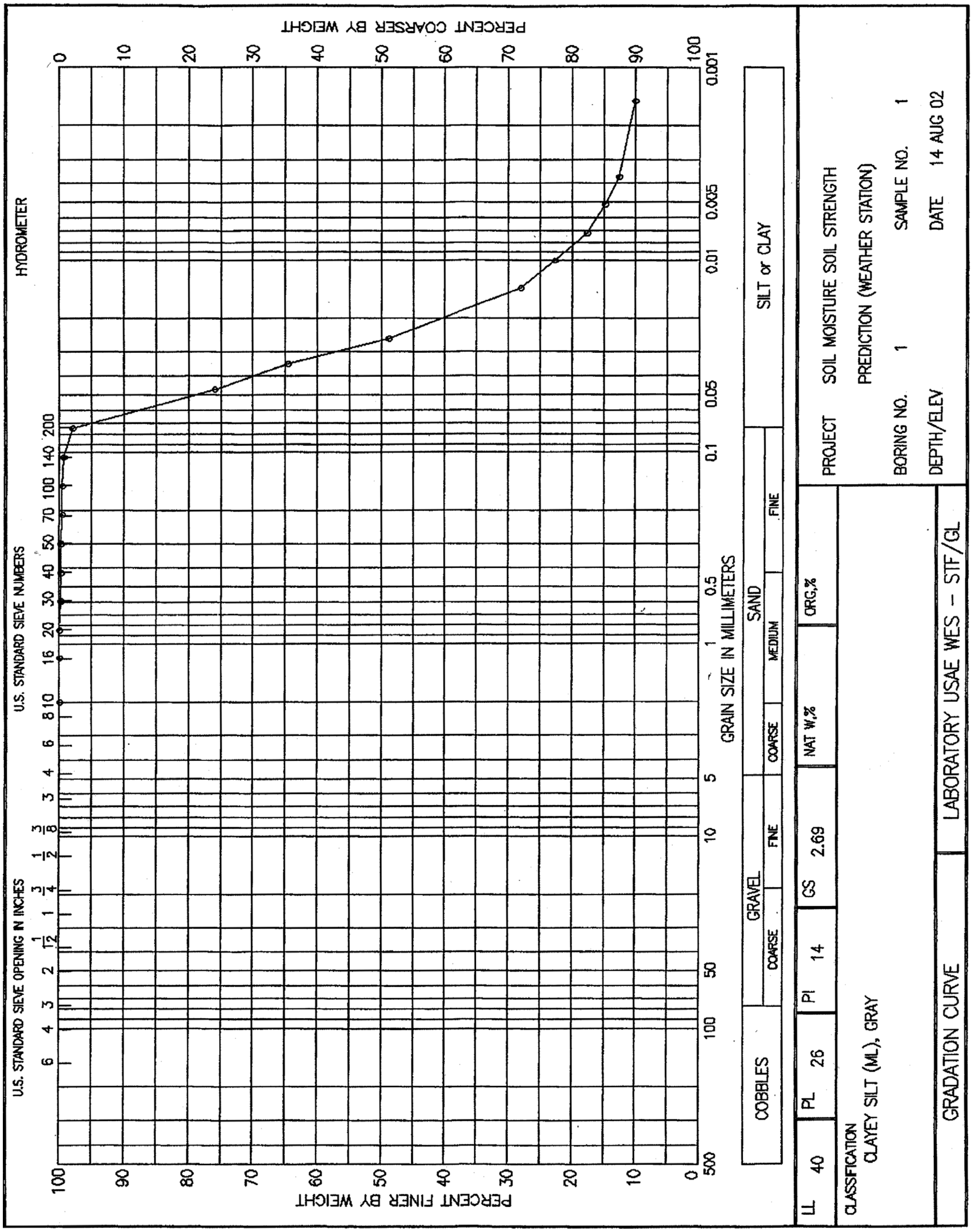


Figure B1. Laboratory analysis/gradation curve (weather station)

SIEVE ANALYSIS

PROJECT: SOIL MOISTURE SOIL STRENGTH
PREDICTION (WEATHER STATION)

BORING: 1 SAMPLE: 1 DF: MASON .DAT
DEPTH: DATE: 14 AUG 02

LL: 40 PL: 26 PI: 14 GS: 2.69 WC: .00
CLASSIFICATION: 108
CLAYEY SILT (ML), GRAY

TOTAL WEIGHT OF SAMPLE: .0 gms.
PARTIAL WEIGHT AFTER SPLIT: 50.5 gms.

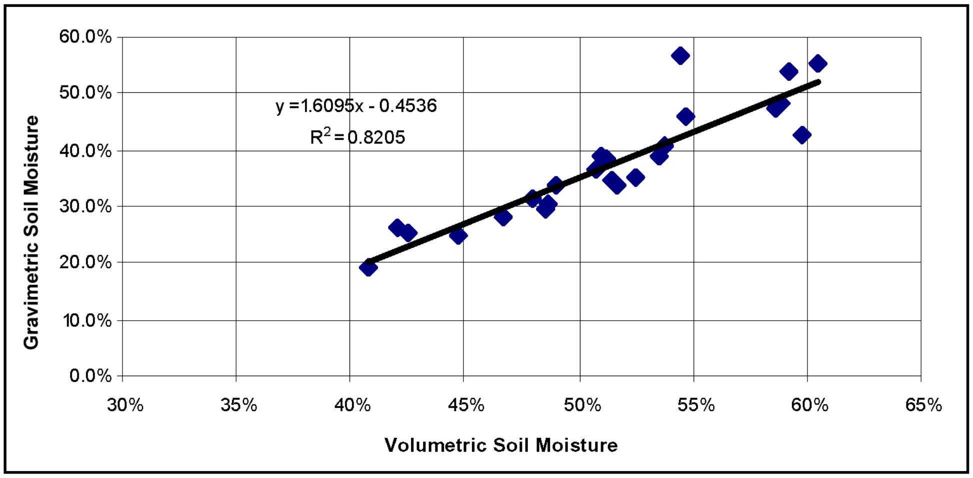
WEIGHTS gm.	SIEVE SIZE or NUMBER	OPENING mm	PERCENT FINER	PERCENT COARSER
.0	No 10	2.000	100.0	.0
.0	No 16	1.180	100.0	.0
.0	No 20	.850	100.0	.0
.1	No 30	.600	99.8	.2
.1	No 40	.425	99.8	.2
.1	No 50	.300	99.8	.2
.2	No 70	.212	99.6	.4
.2	No 100	.150	99.6	.4
.3	No 140	.106	99.4	.6
1.0	No 200	.075	98.0	2.0
HYDROMETER:				
RDGS	TEMP			
23.8	24.0	.0473	76.0	24.0
20.2	24.0	.0347	64.6	35.4
15.2	24.0	.0258	48.9	51.1
8.6	24.0	.0141	28.1	71.9
6.9	24.0	.0101	22.7	77.3
5.3	24.0	.0072	17.7	82.3
4.4	24.0	.0051	14.8	85.2
4.1	22.0	.0037	12.6	87.4
2.9	24.0	.0015	10.1	89.9

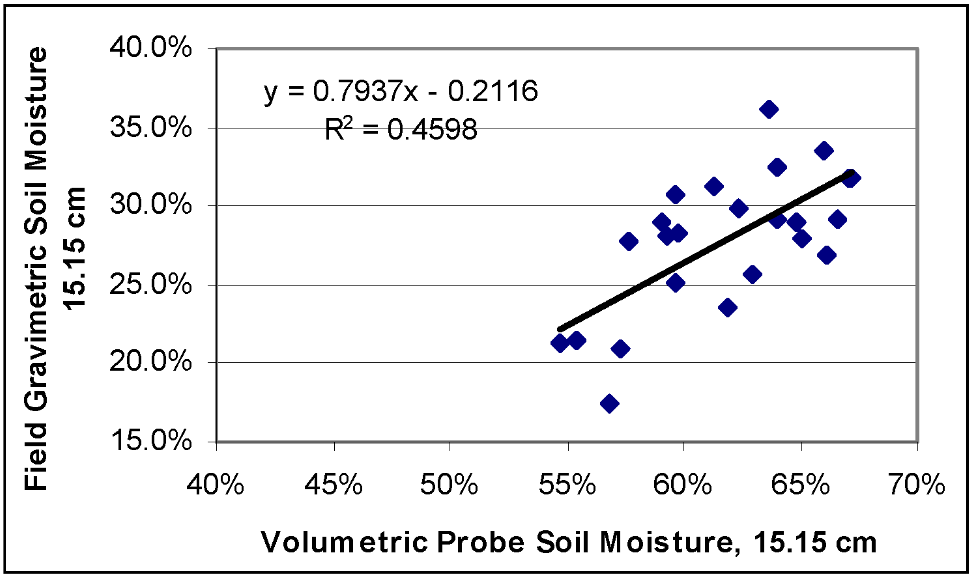
PERCENT GRAVEL = .0
PERCENT SAND = 2.0
PERCENT FINES = 98.0

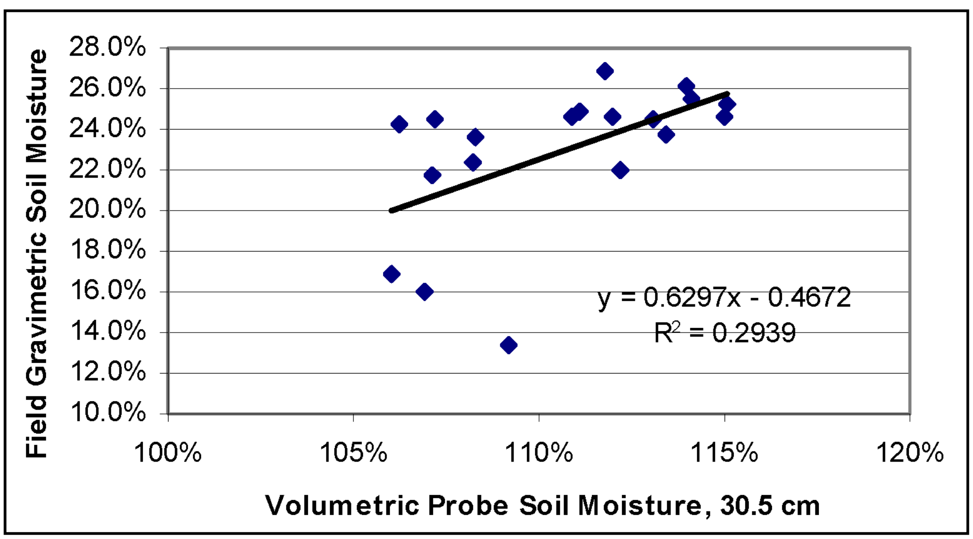
EDE

Figure B2. Sieve analysis (weather station)

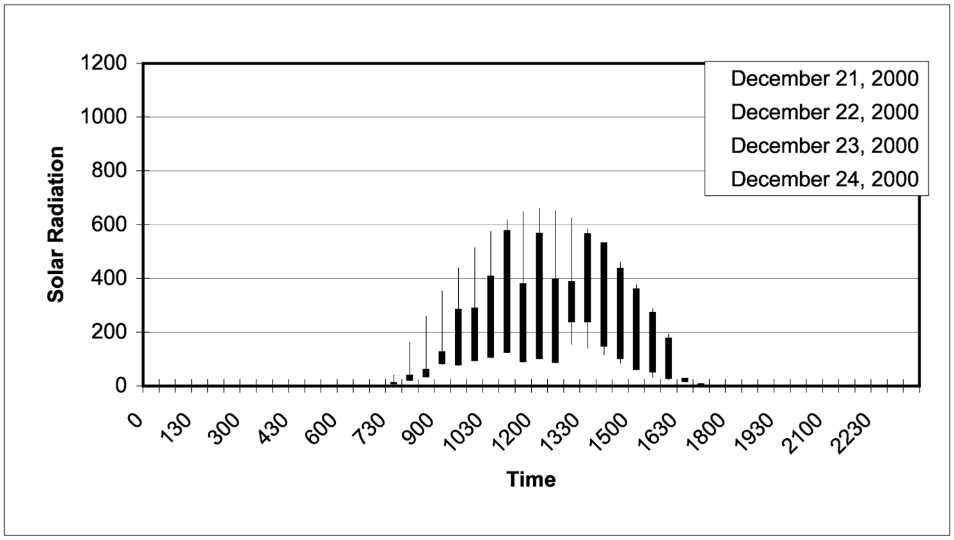
Appendix C
Plates Comparing Measured Field Moisture to Probe Moisture

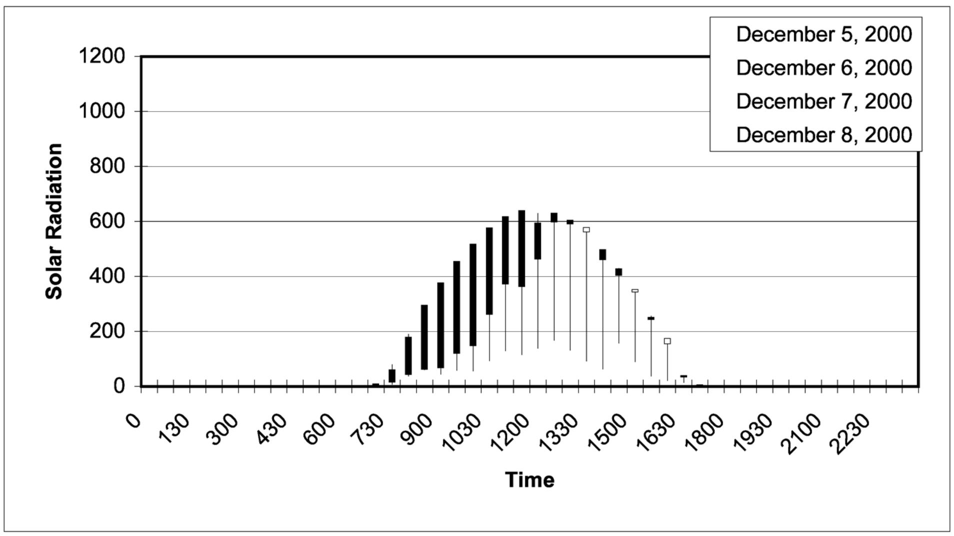

60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Gravimetric Soil Moisture
y =1.6095x - 0.4536
R2 = 0.8205
30%
35%
40%
45%
50%
55%
60%
65%
Volumetric Soil Moisture

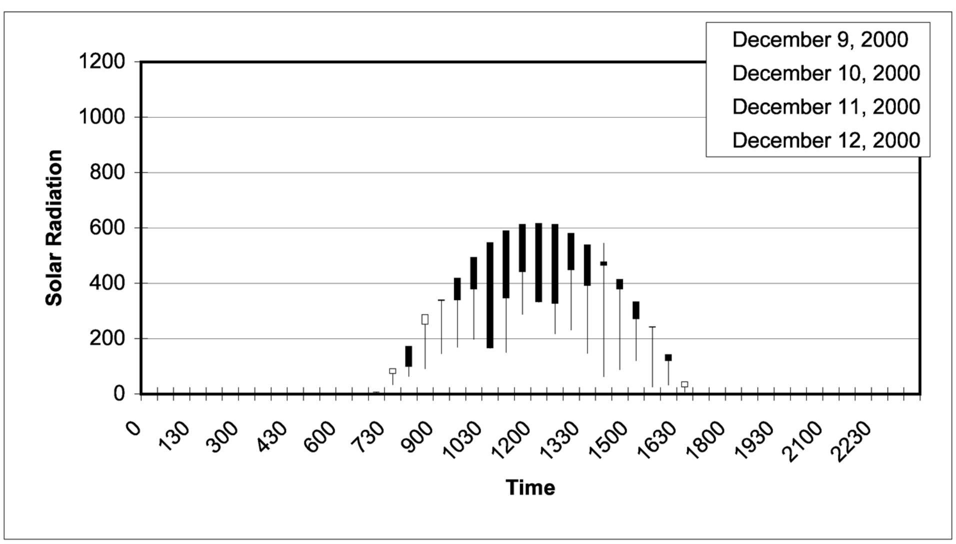

40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
Field Gravimetric Soil Moisture 15.15 cm
y = 0.7937x - 0.2116
R2 = 0.4598
40%
45%
50%
55%
60%
65%
70%
Volumetric Probe Soil Moisture, 15.15 cm

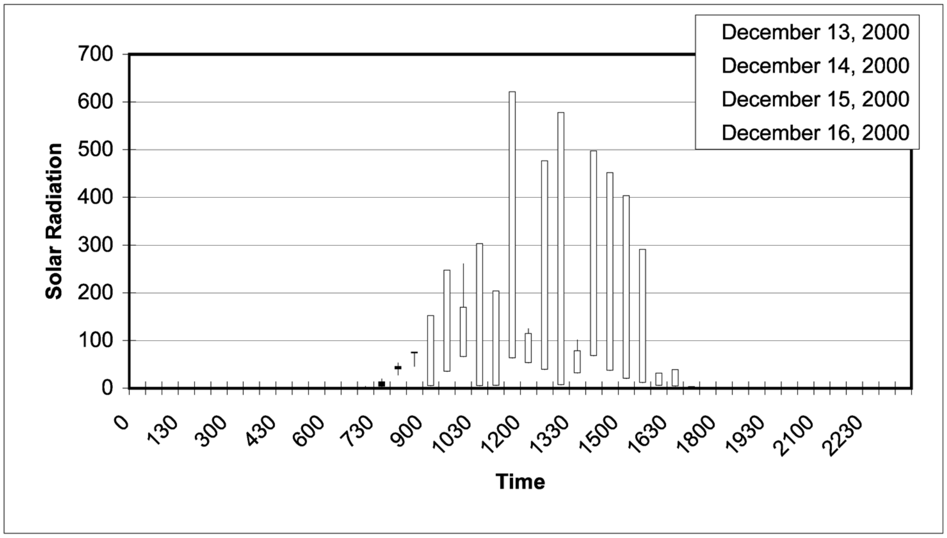

28.0%
26.0%
24.0%
22.0%
20.0%
18.0%
16.0%
14.0%
12.0%
10.0%
Field Gravimetric Soil Moisture
y = 0.6297x - 0.4672
R2 = 0.2939
100%
105%
110%
115%
120%
Volumetric Probe Soil Moisture, 30.5 cm

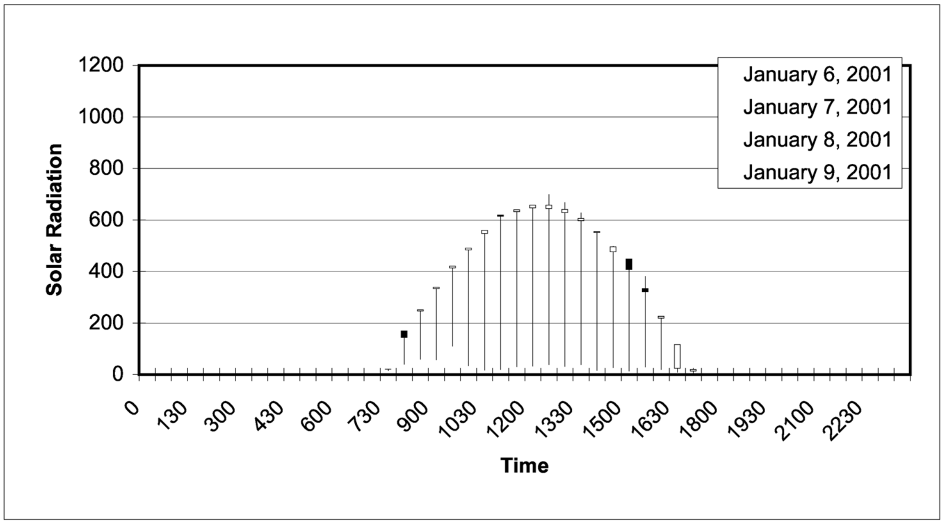
Appendix D
Solar Radiation


December 21, 2000
December 22, 2000
December 23, 2000
December 24, 2000
Solar Radiation
Time
0
200
400
600
800
1000
1200
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230


December 5, 2000
December 6, 2000
December 7, 2000
December 8, 2000
Solar Radiation
Time
0
200
400
600
800
1000
1200
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230


December 9, 2000
December 10, 2000
December 11, 2000
December 12, 2000
Solar Radiation
Time
0
200
400
600
800
1000
1200
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230


December 13, 2000
December 14, 2000
December 15, 2000
December 16, 2000
Solar Radiation
700
600
500
400
300
200
100
0
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time


1200
1000
800
600
400
200
0
Solar Radiation
January 6, 2001
January 7, 2001
January 8, 2001
January 9, 2001
0
130
300
430
600
730
900
1030
1200
1330
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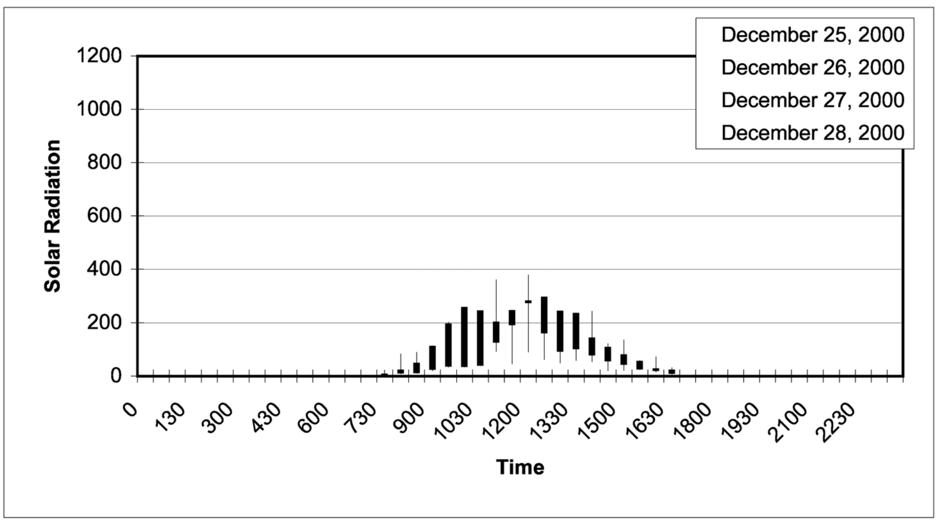
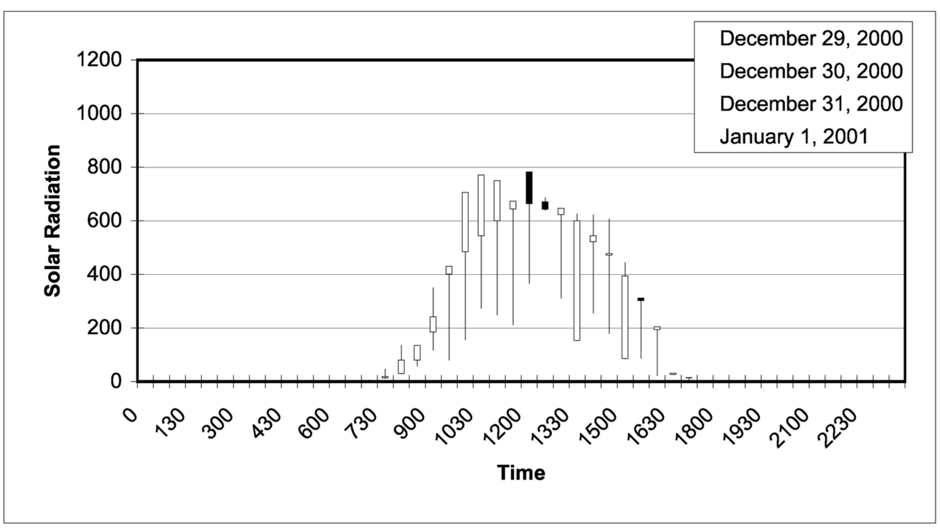
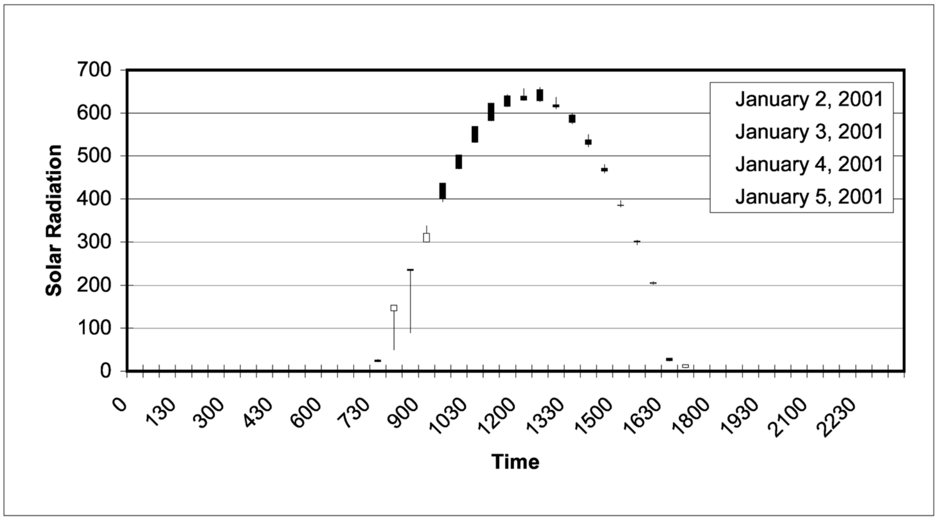
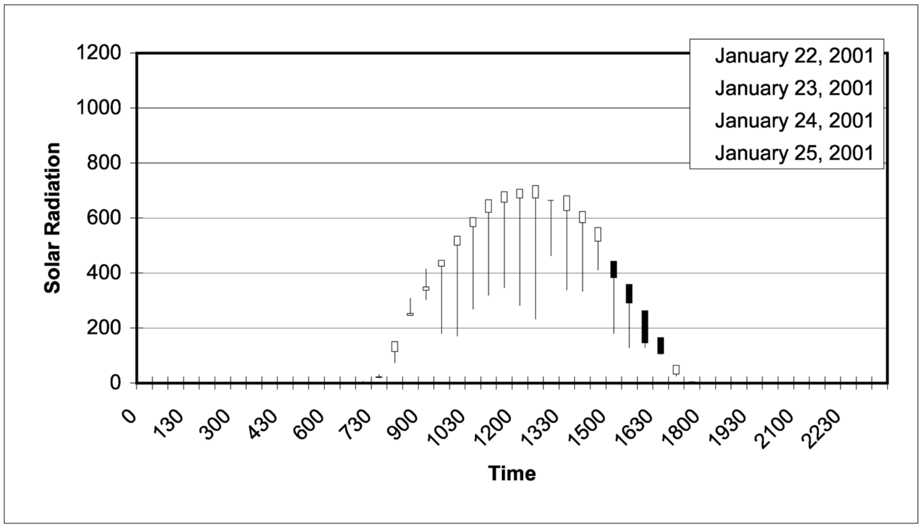
1630
1800
1930
2100
2230
Time

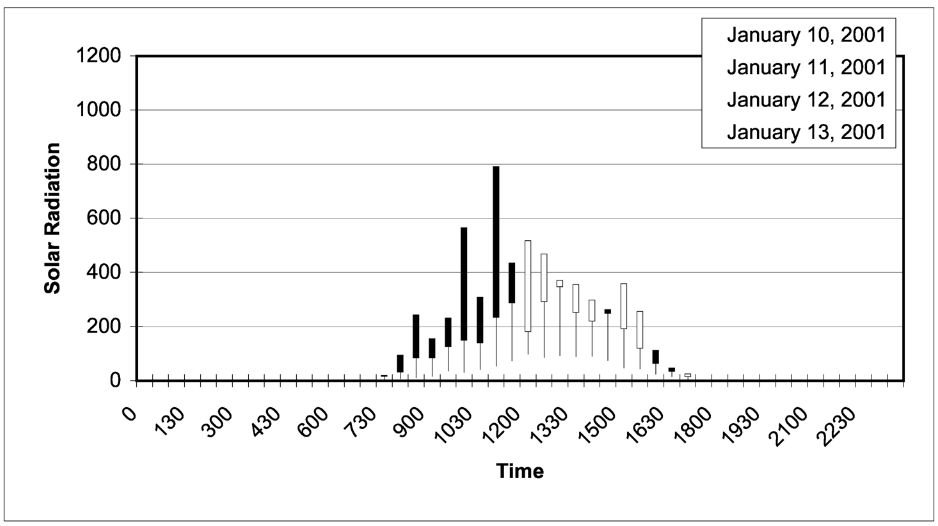

1200
1000
800
600
400
200
0
Solar Radiation
December 25, 2000
December 26, 2000
December 27, 2000
December 28, 2000
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time


1200
1000
800
600
400
200
0
Solar Radiation
December 29, 2000
December 30, 2000
December 31, 2000
January 1, 2001
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time


700
600
500
400
300
200
100
0
Solar Radiation
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time
January 2, 2001
January 3, 2001
January 4, 2001
January 5, 2001



January 22, 2001
January 23, 2001
January 24, 2001
January 25, 2001
Solar Radiation
1200
1000
800
600
400
200
0
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time



January 10, 2001
January 11, 2001
January 12, 2001
January 13, 2001
Solar Radiation
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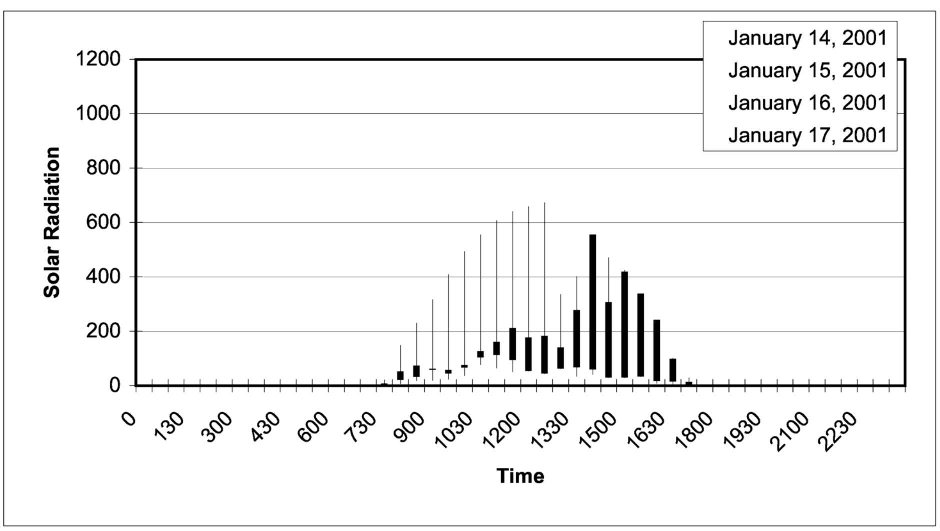
2100
2230
Time



January 14, 2001
January 15, 2001
January 16, 2001
January 17, 2001
Solar Radiation
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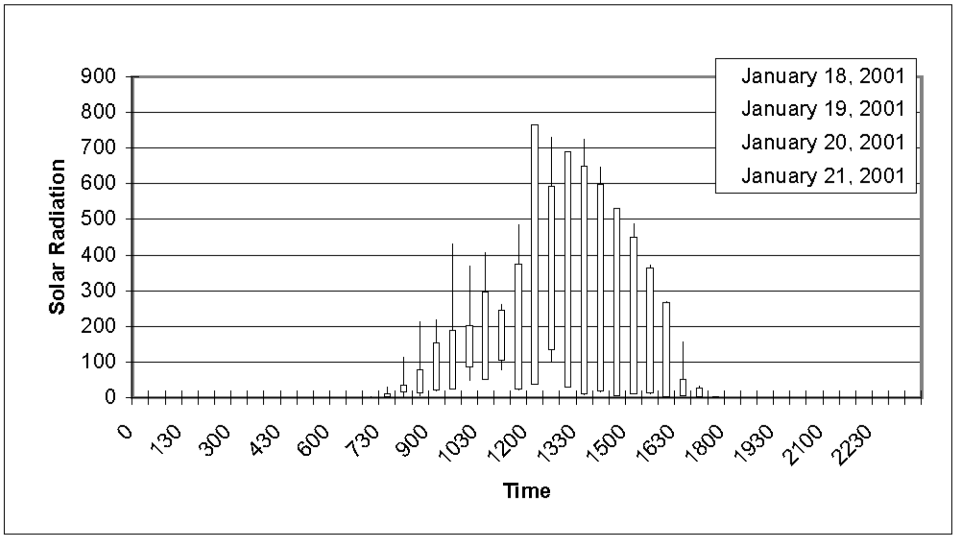
1930
2100
2230
Time



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January 21, 2001
Solar Radiation
900
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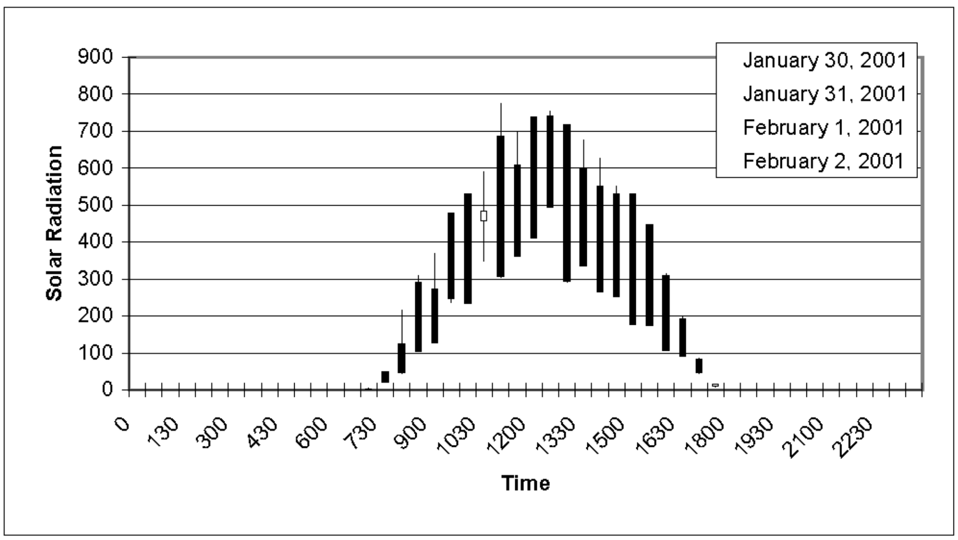
2230
Time



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January 31, 2001
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February 2, 2001
Solar Radiation
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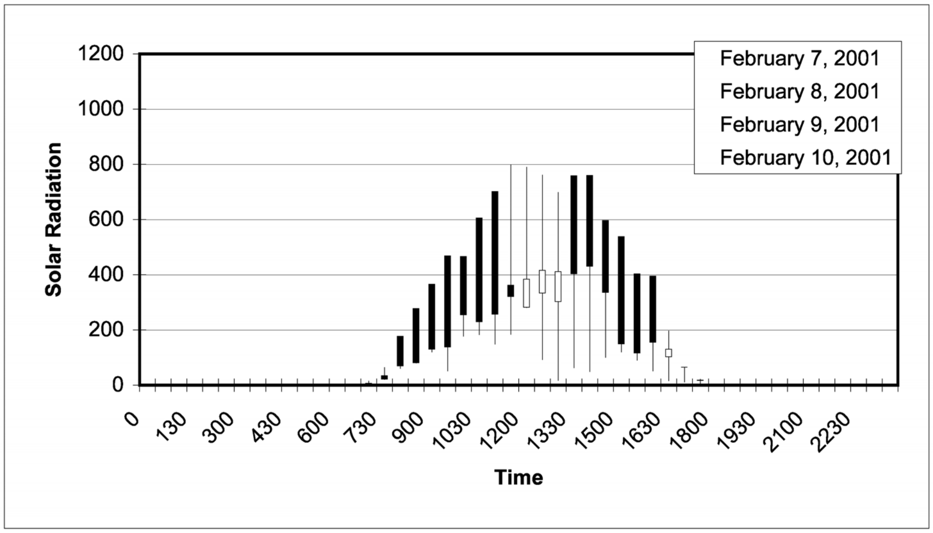
2230
Time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February 10, 2001
Solar Radiation
Time
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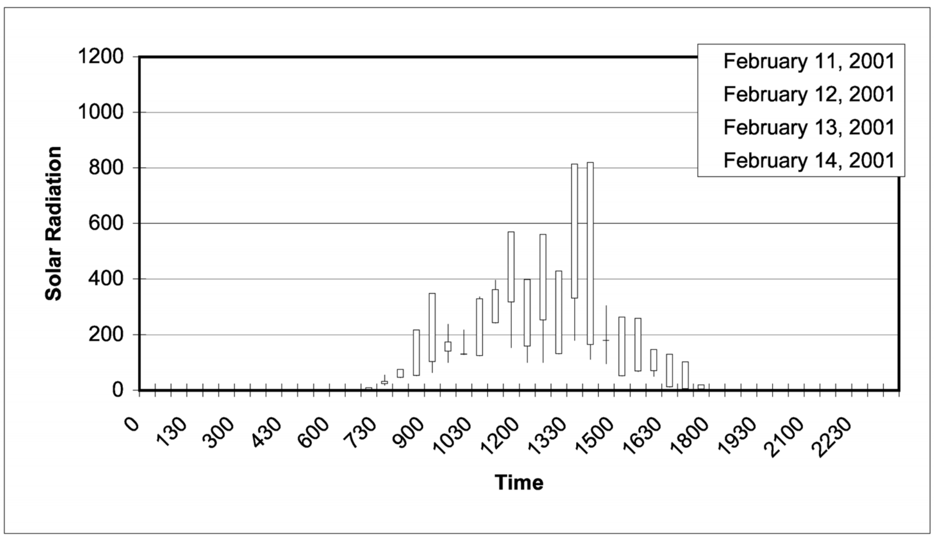
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Solar Radiation
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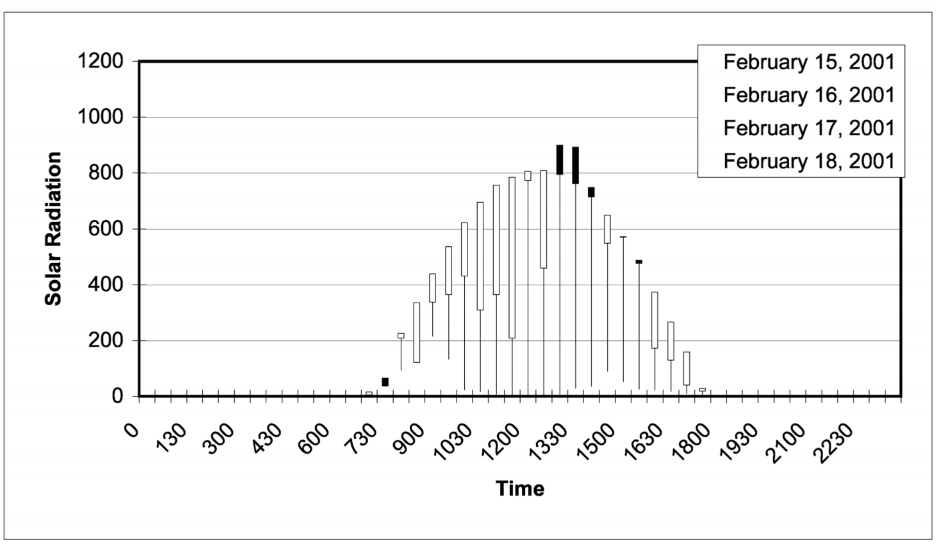
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Solar Radiation
Time
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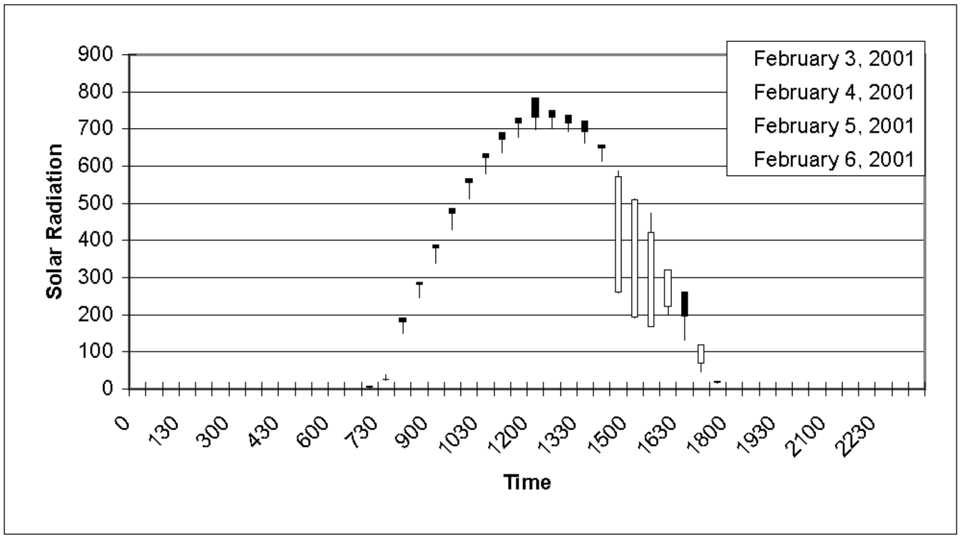

Solar Radiation
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Time
February 3, 2001
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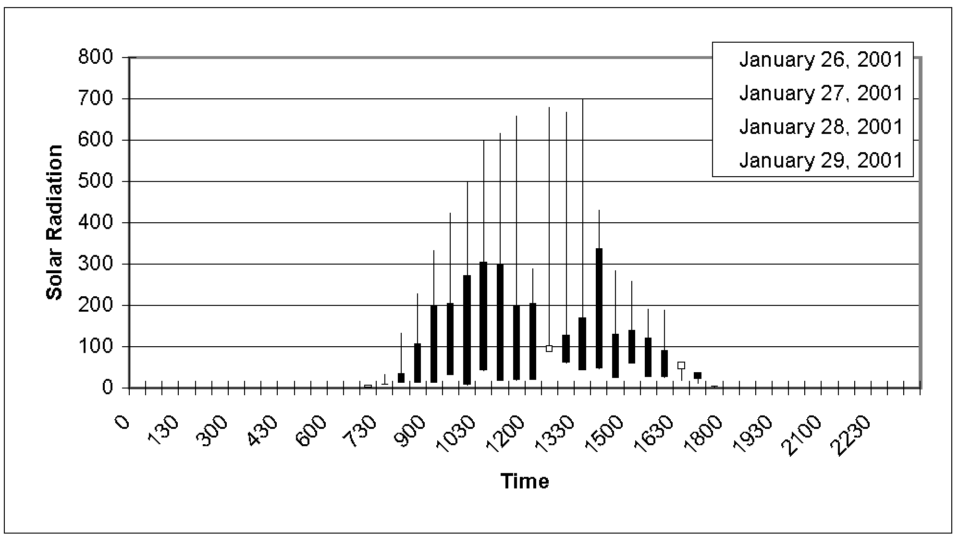
February 5, 2001
February 6, 2001



Solar Radiation
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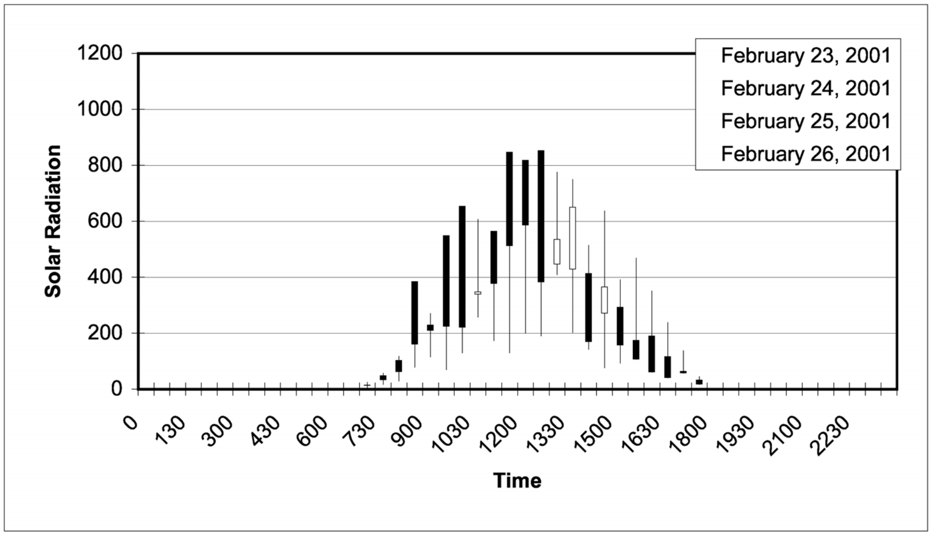
2230
Time
January 26, 2001
January 27, 2001
January 28, 2001
January 29, 2001


February 23, 2001
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February 26, 2001
Solar Radiation
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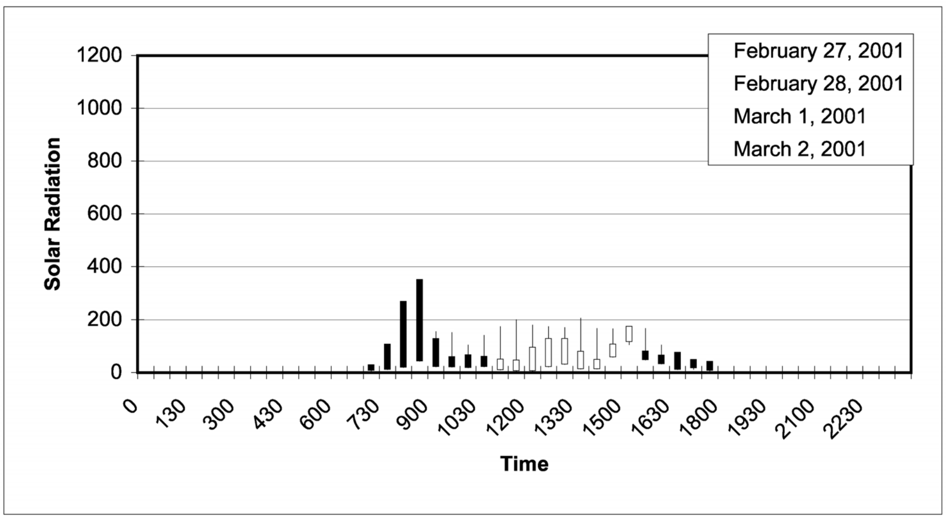
2100
2230
Time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March 2, 2001
Solar Radiation
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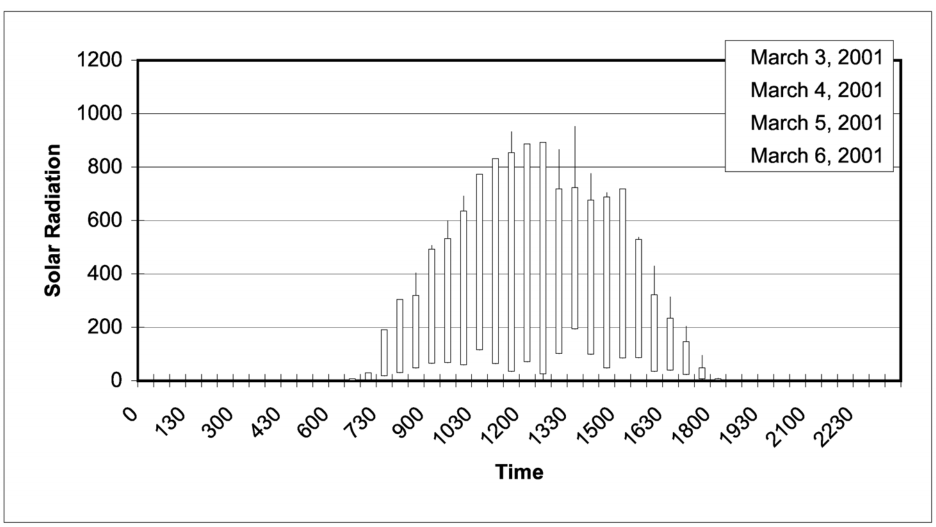
Time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Solar Radiation
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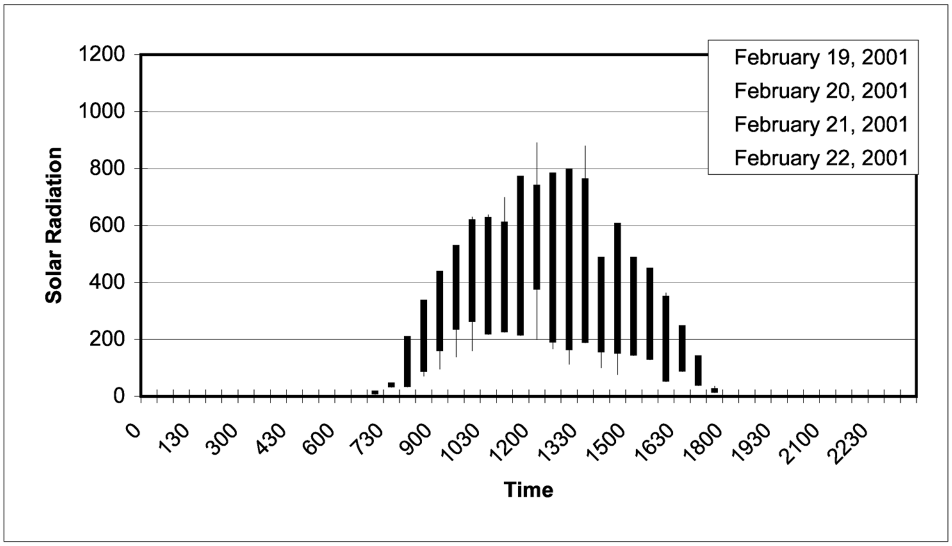
Time



February 19, 2001
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February 22, 2001
Solar Radiation
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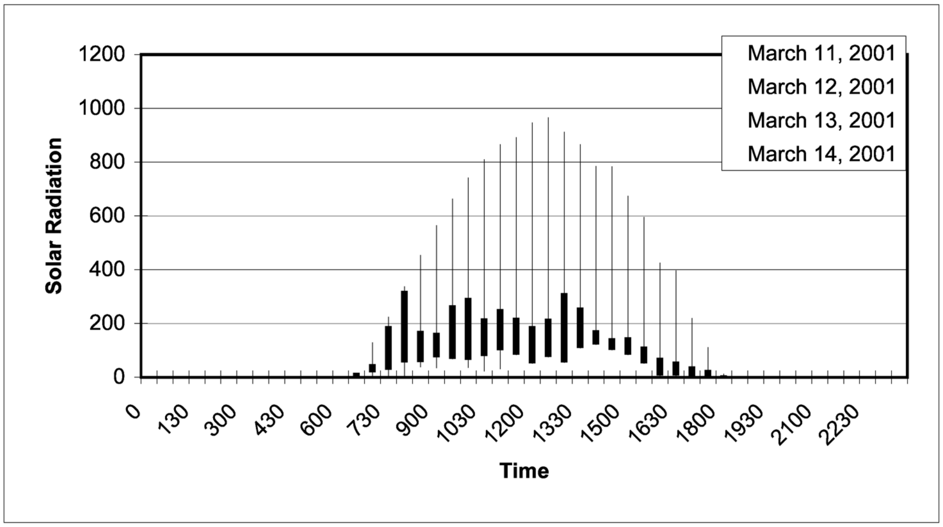
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Solar Radiation
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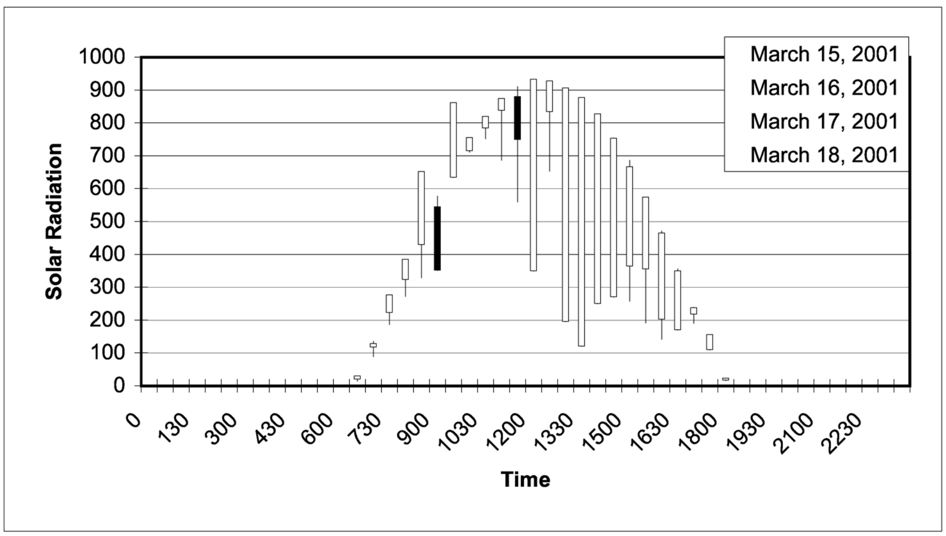
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March 18, 2001
Solar Radiation
Time
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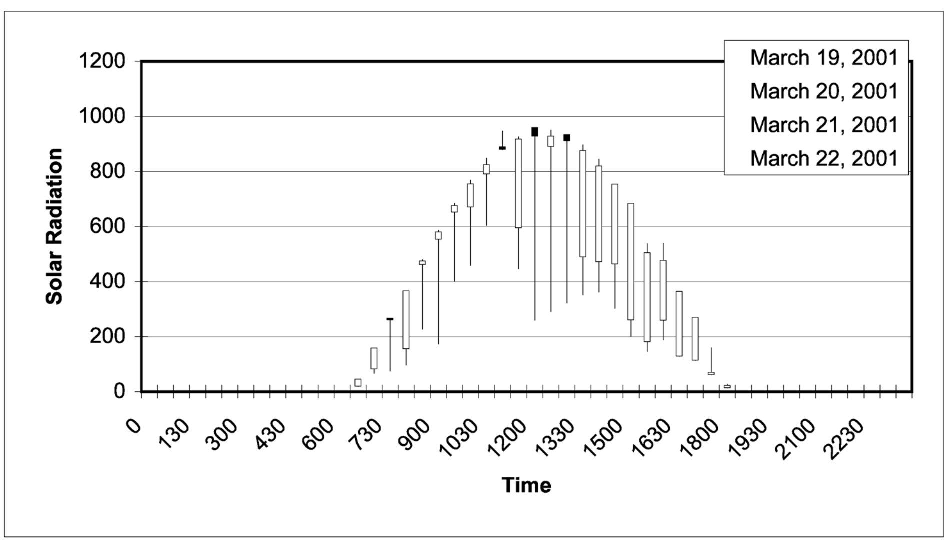
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March 21, 2001
March 22, 2001
Solar Radiation
Time
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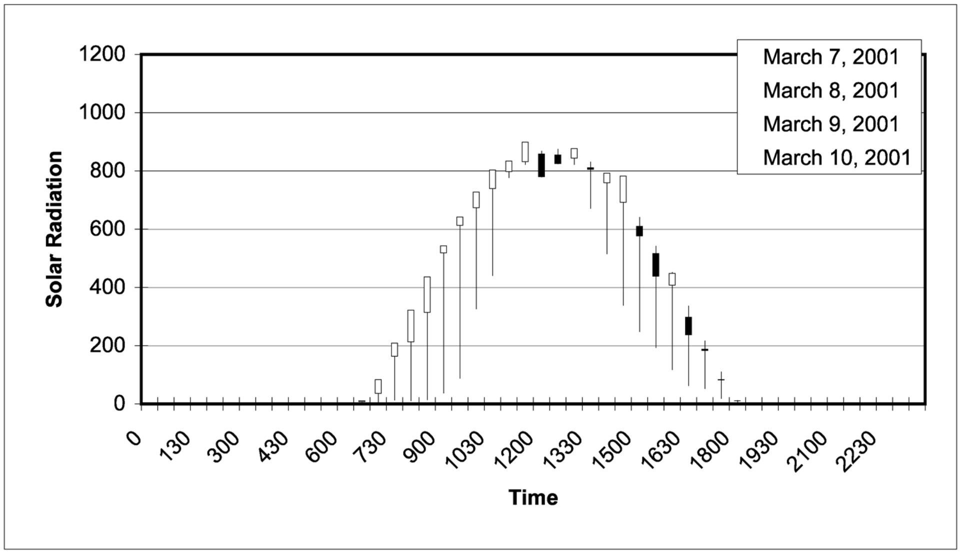
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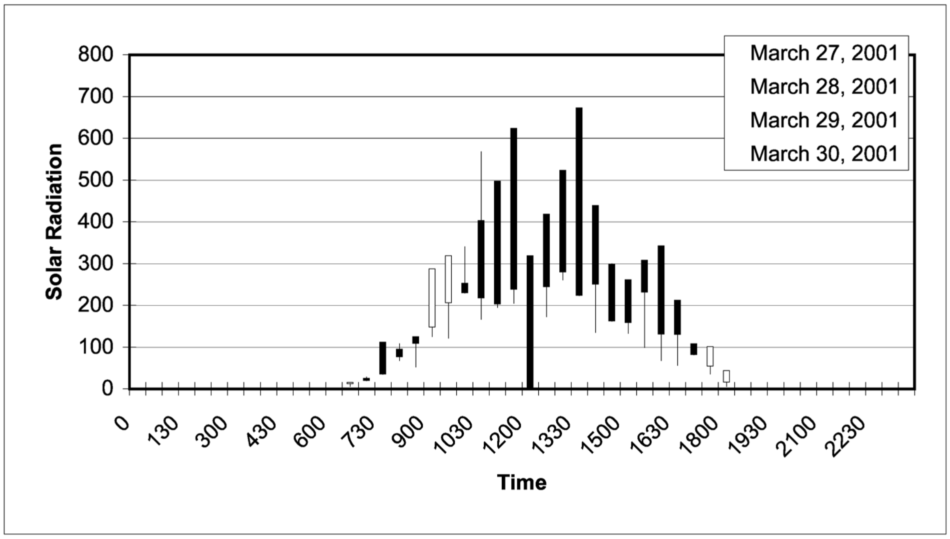
2230
Time
March 7, 2001
March 8, 2001
March 9, 2001
March 10, 2001


March 27, 2001
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Solar Radiation
Time
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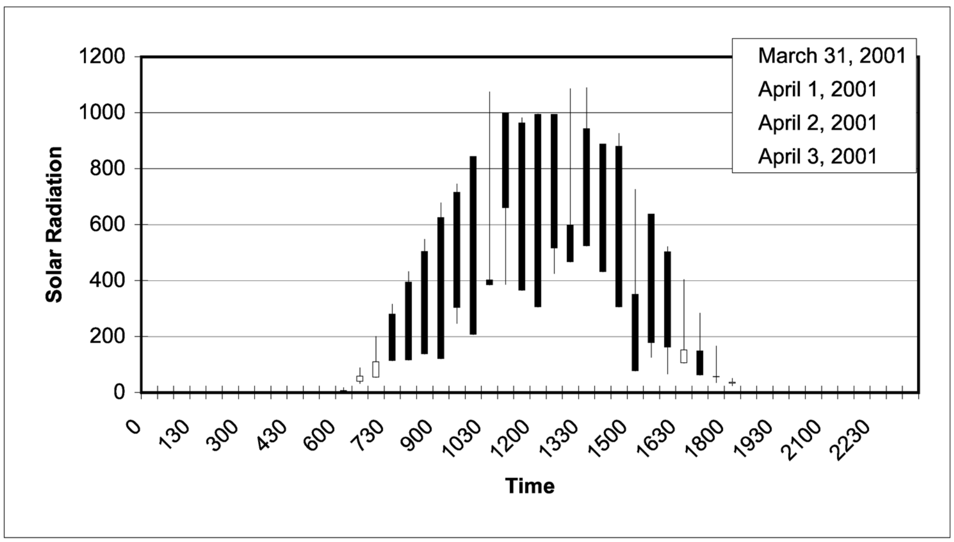
March 31, 2001
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April 3, 2001
Solar Radiation
Time
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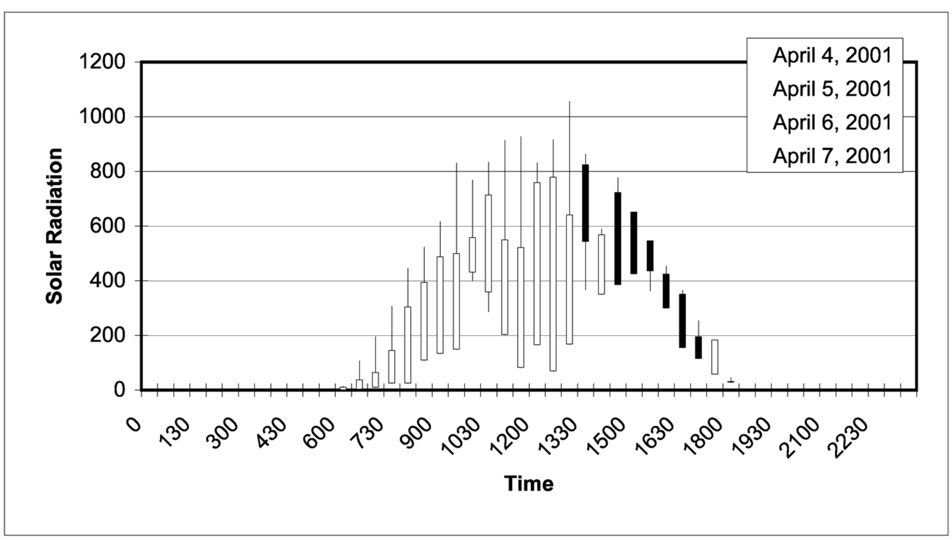
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Solar Radiation
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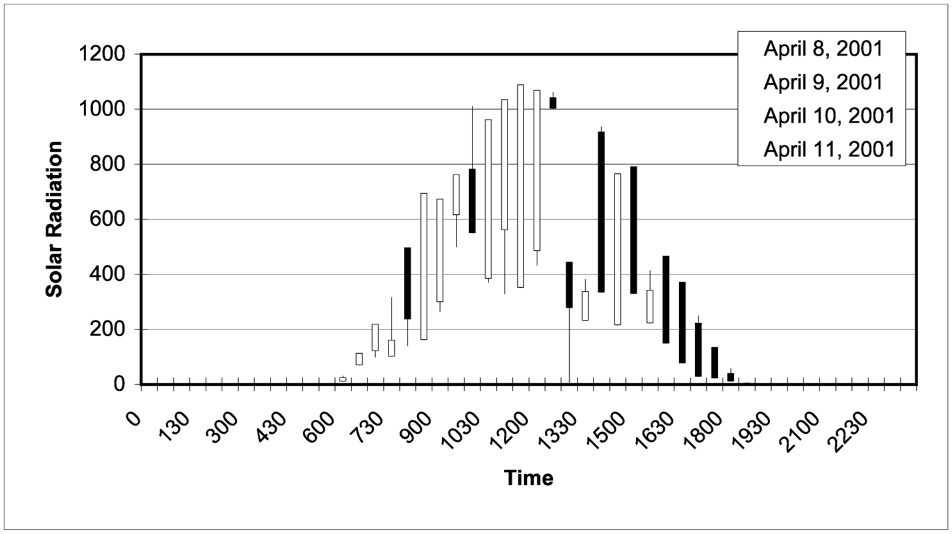
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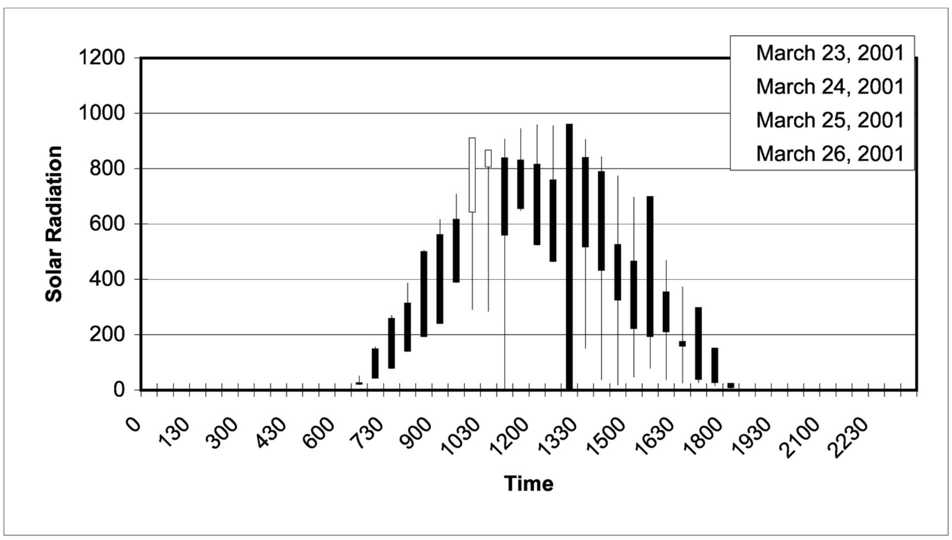
March 23, 2001
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March 25, 2001
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Solar Radiation
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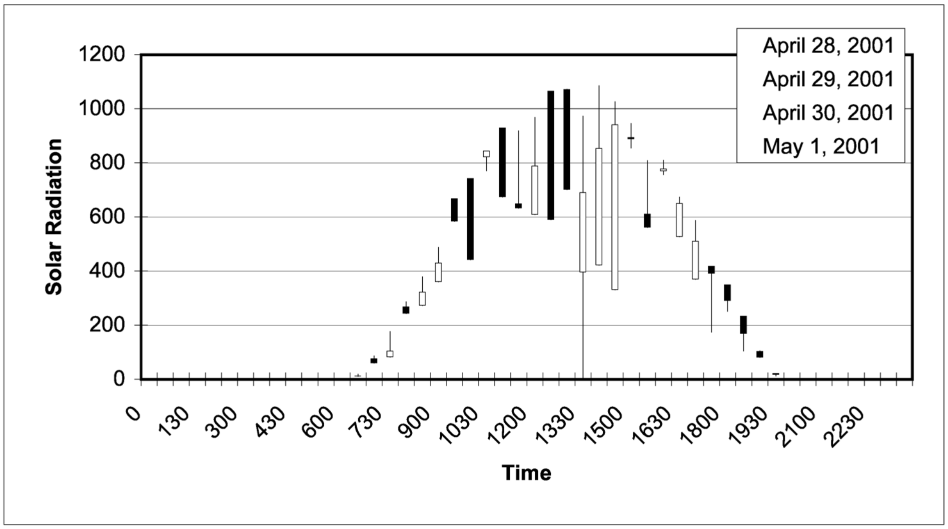

April 28, 2001
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May 1, 2001
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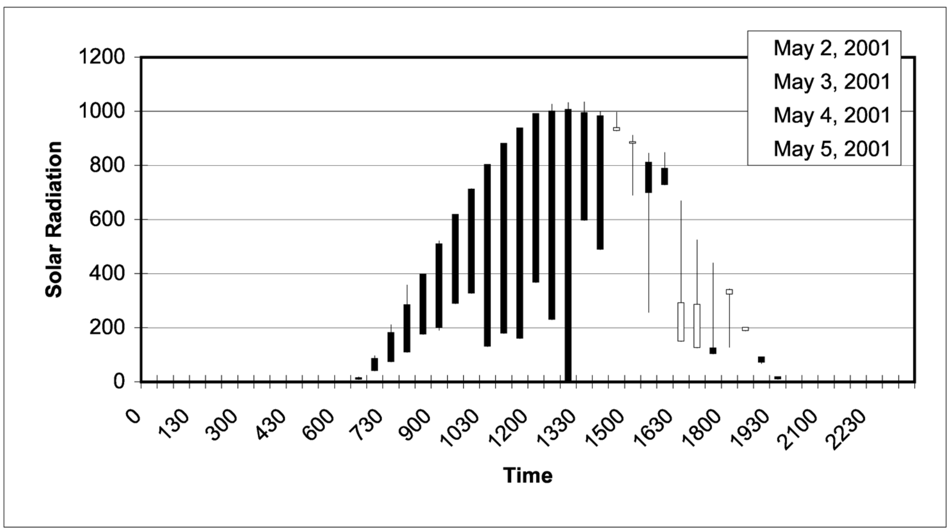
Time



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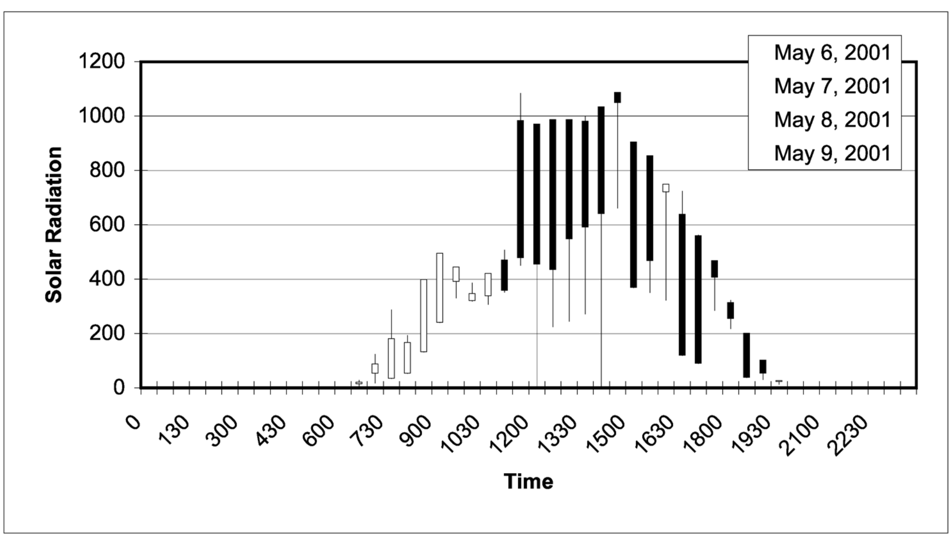
Time



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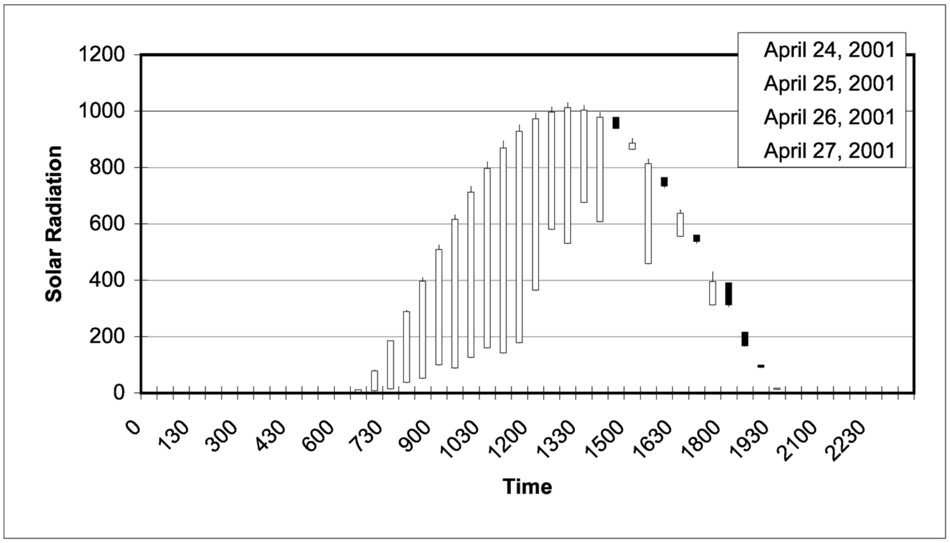
Time


April 24, 2001
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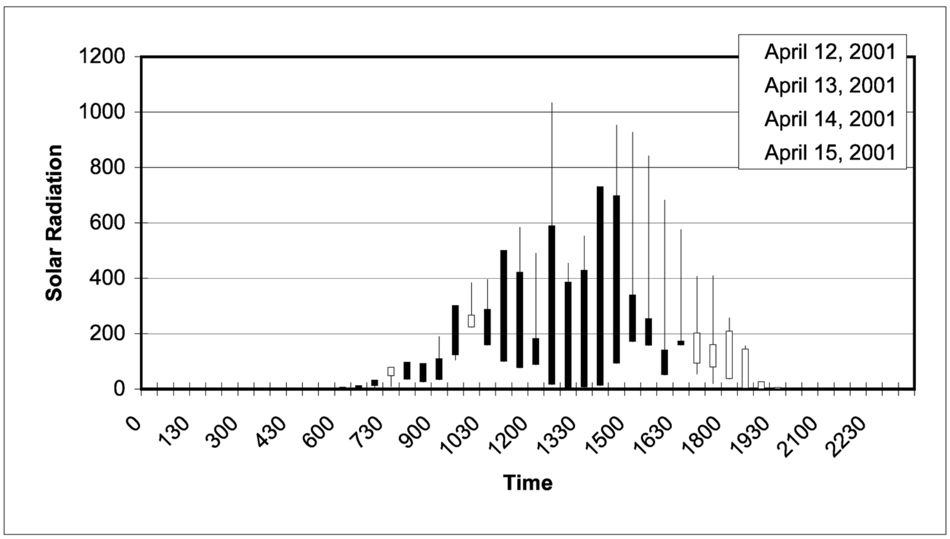
Time


April 12, 2001
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April 15, 2001
Solar Radiation
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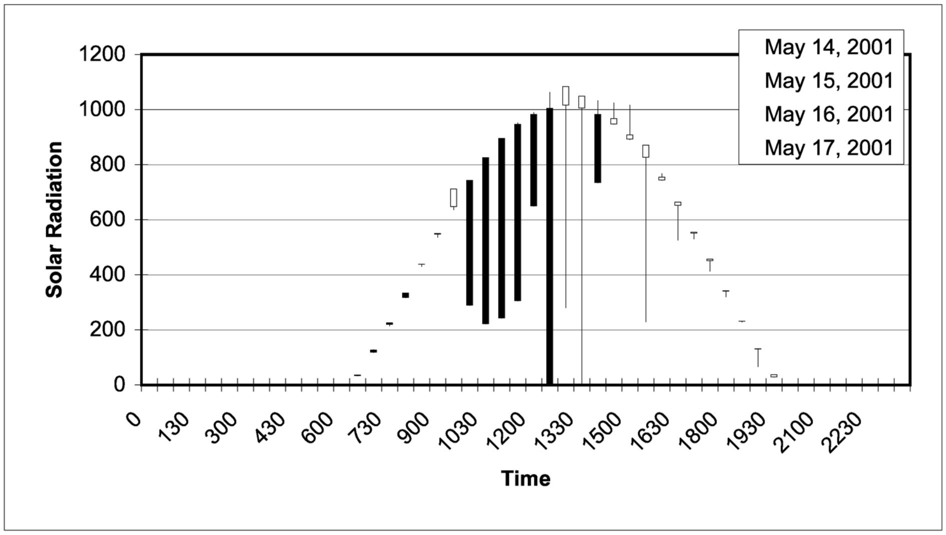

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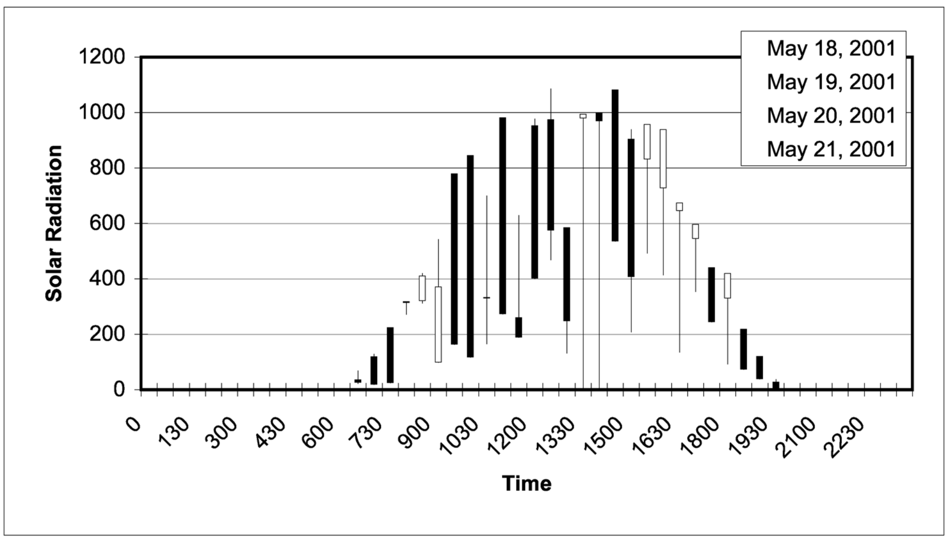
May 17, 2001
Solar Radiation
Time



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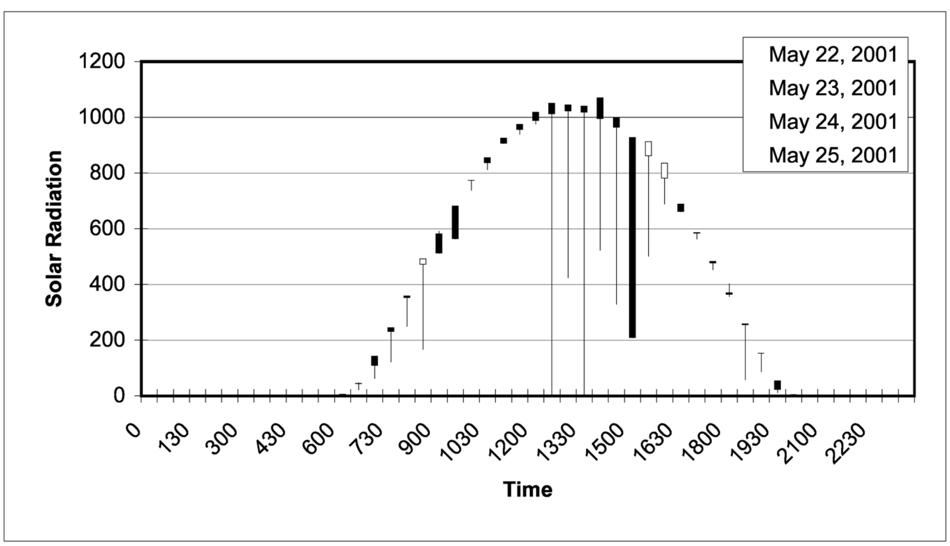
May 20, 2001
May 21, 2001
Solar Radiation
Time



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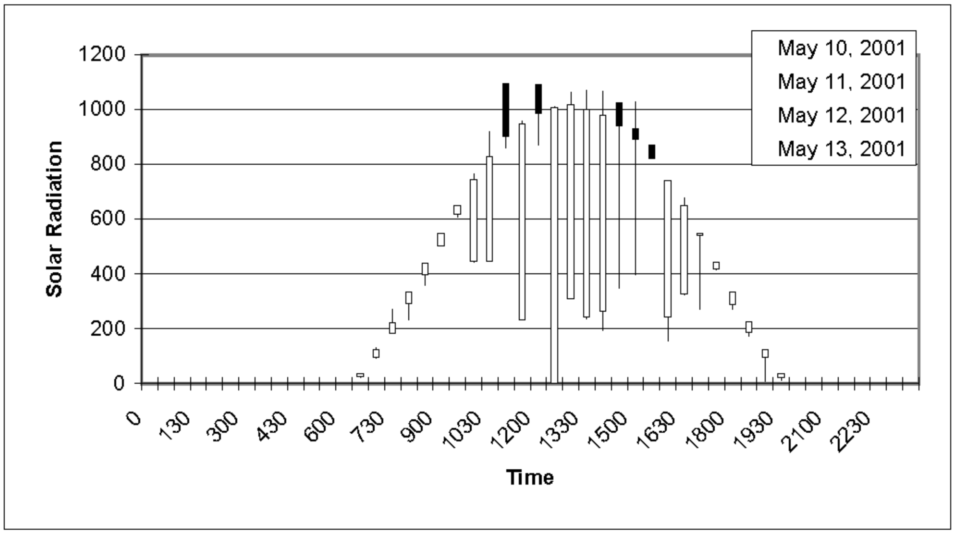
May 25, 2001
Solar Radiation
Time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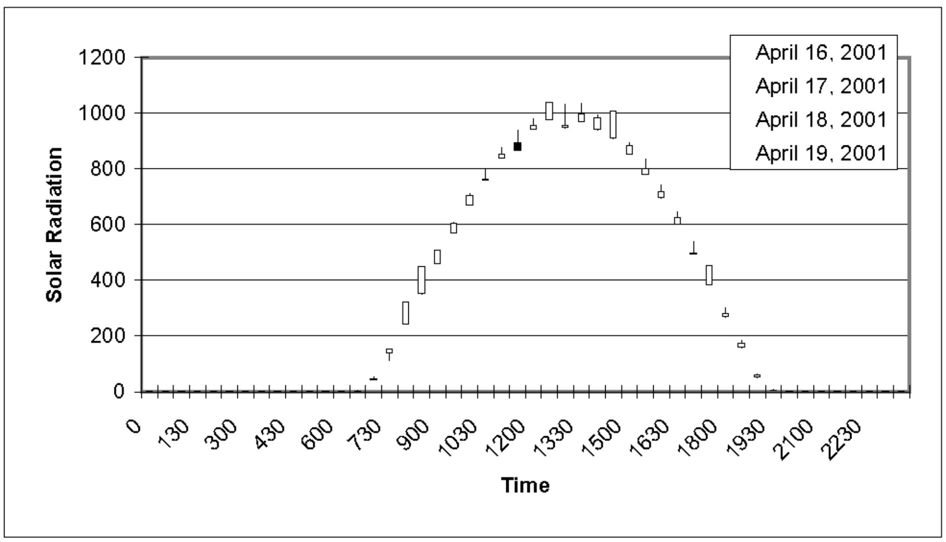
Time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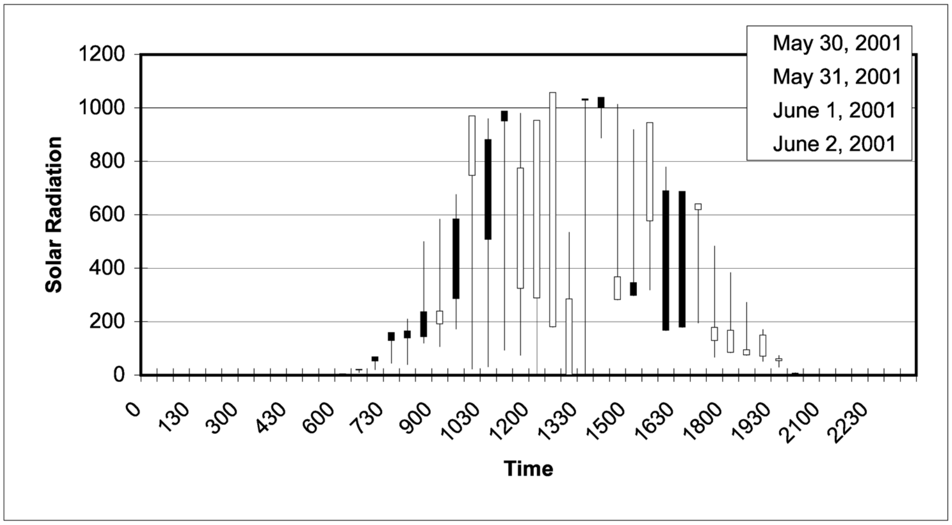

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June 2, 2001
Solar Radiation
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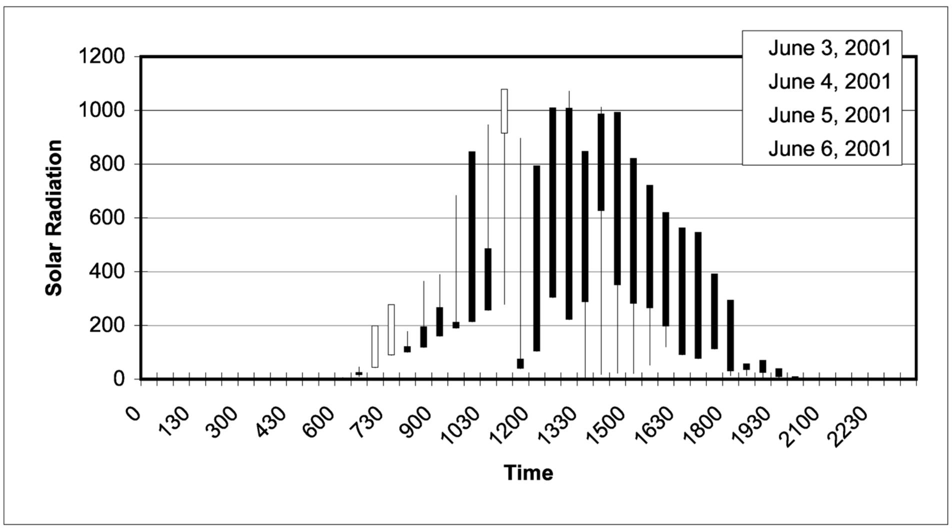
Time



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June 6, 2001
Solar Radiation
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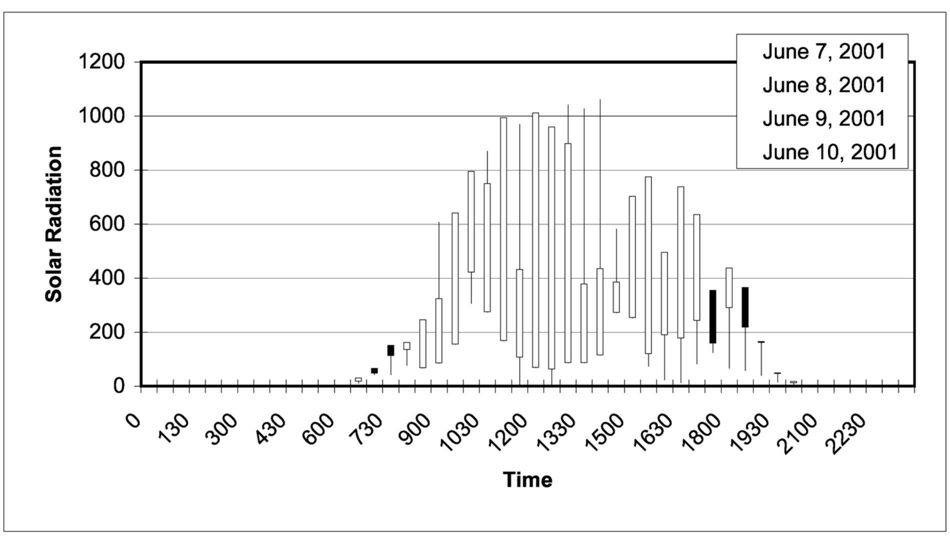
Time



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Solar Radiation
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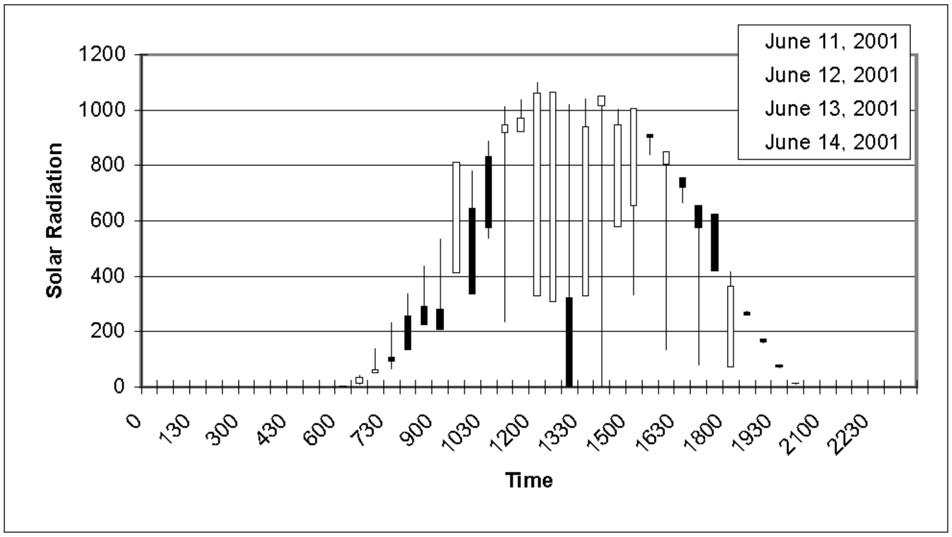
Time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Solar Radiation
Time
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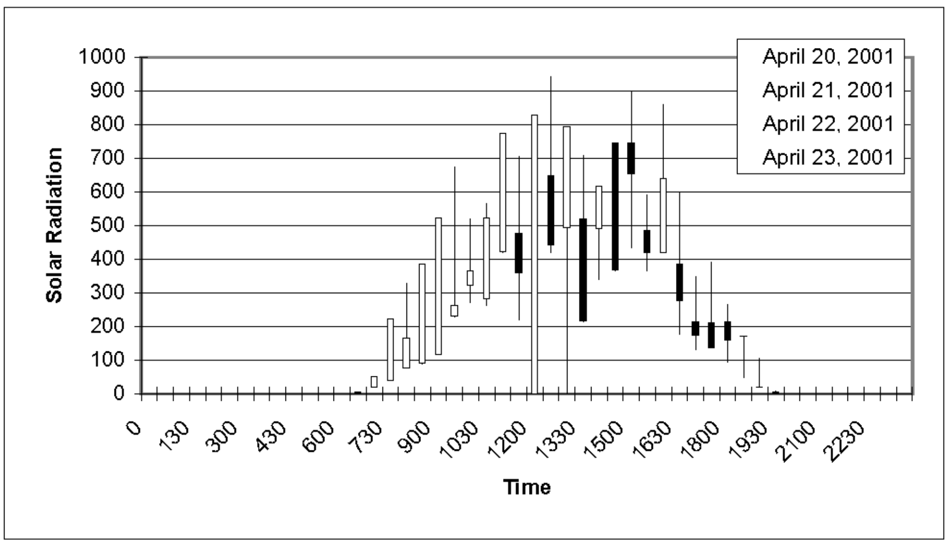
April 20, 2001
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April 23, 2001
Solar Radiation
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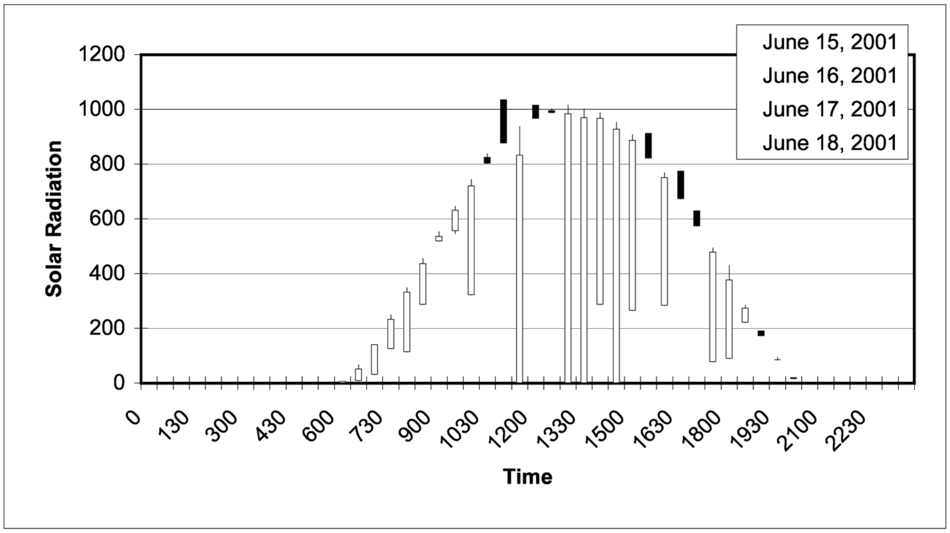
June 15, 2001
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June 17, 2001
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Solar Radiation
Time
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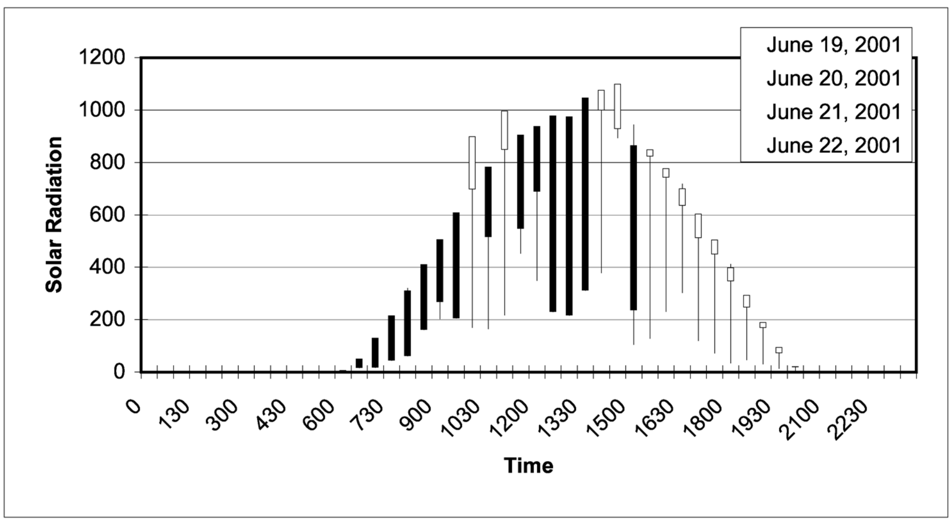
June 19, 2001
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Solar Radiation
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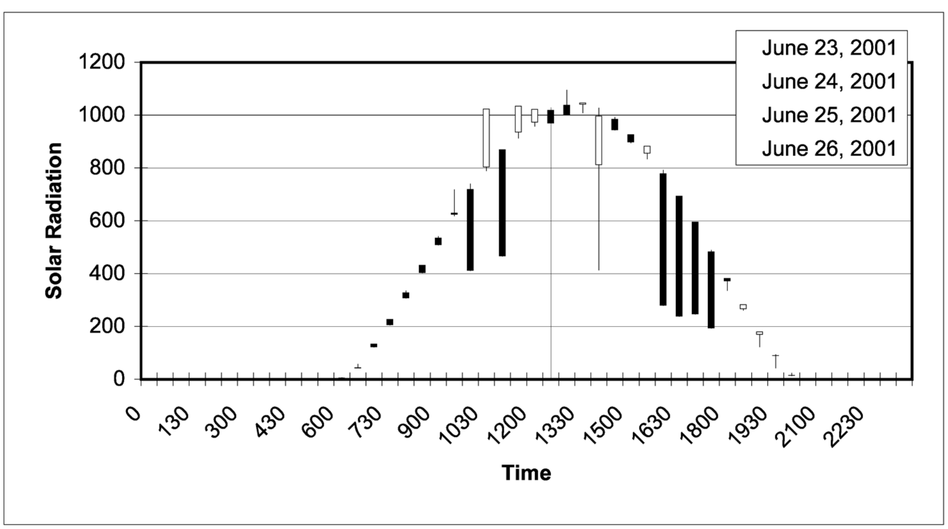
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Solar Radiation
Time
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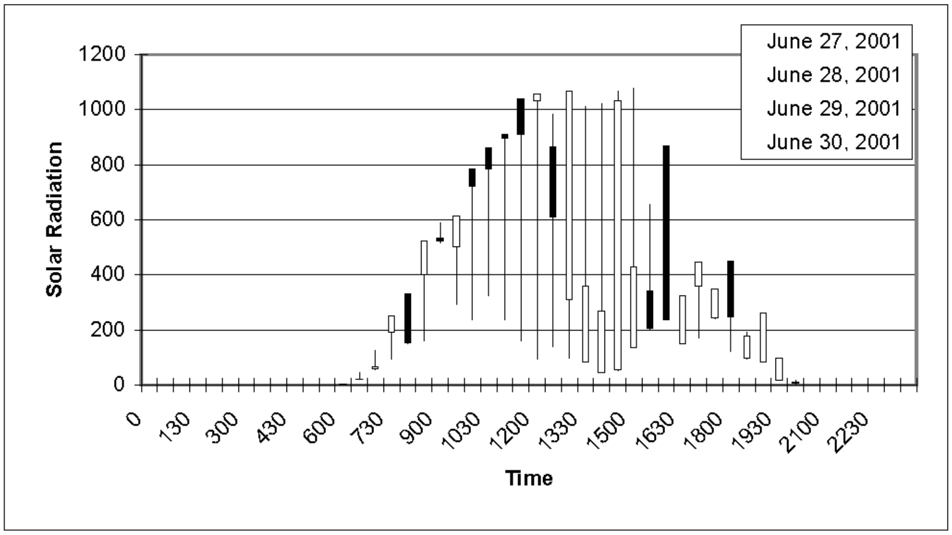

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June 28, 2001
June 29, 2001
June 30, 2001
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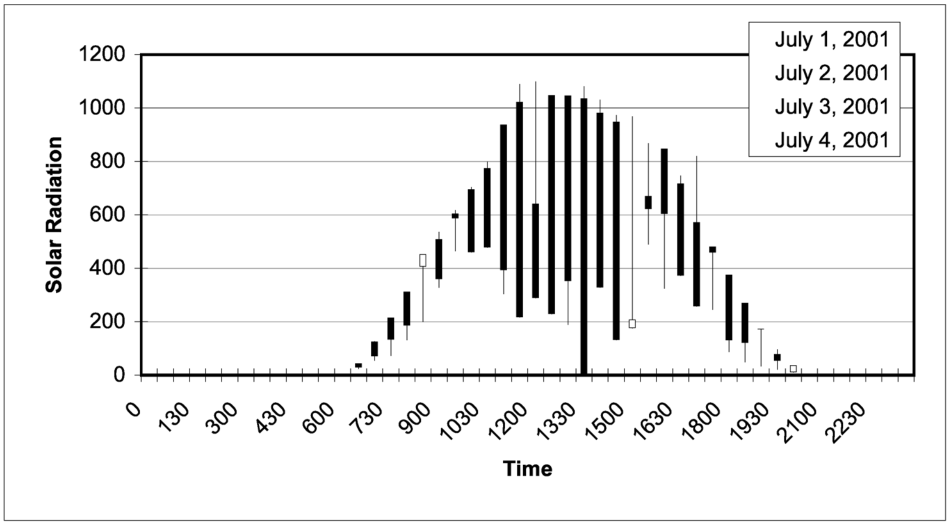
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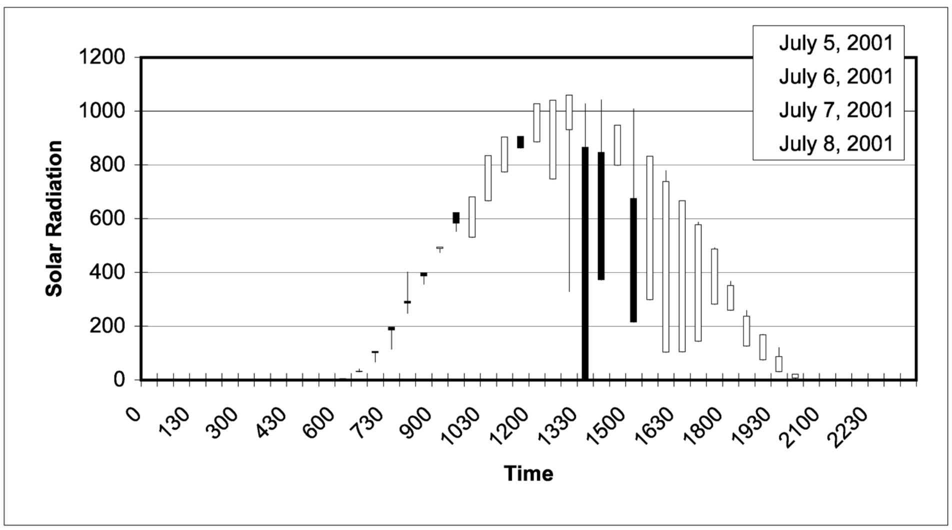
Time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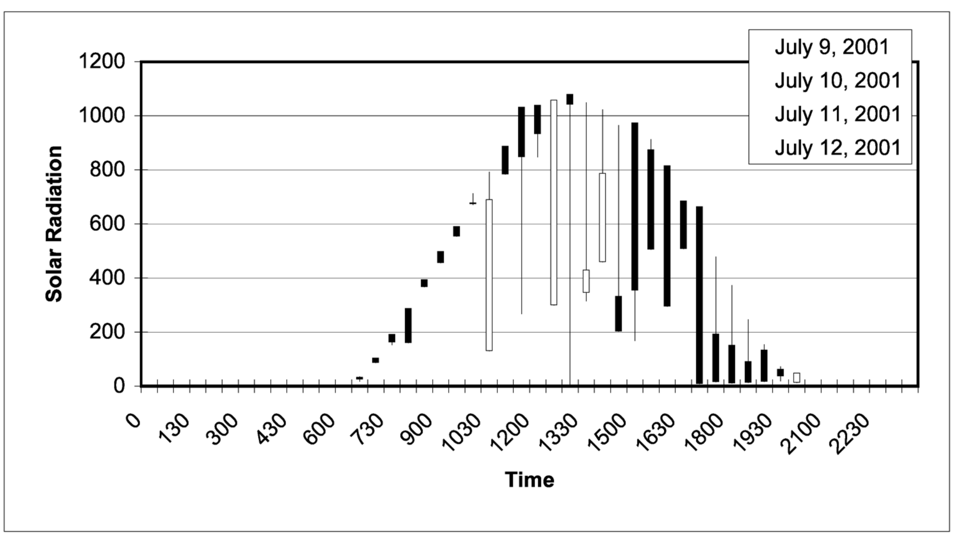
Time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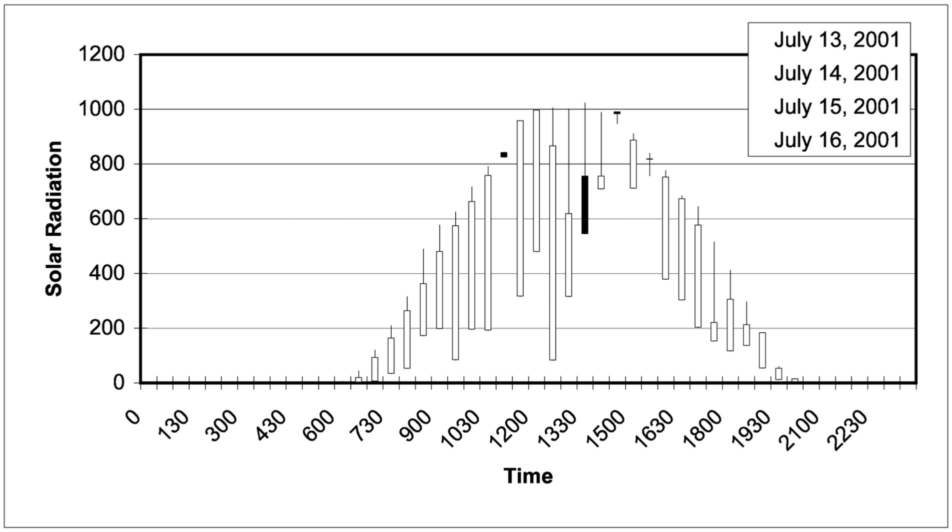
July 13, 2001
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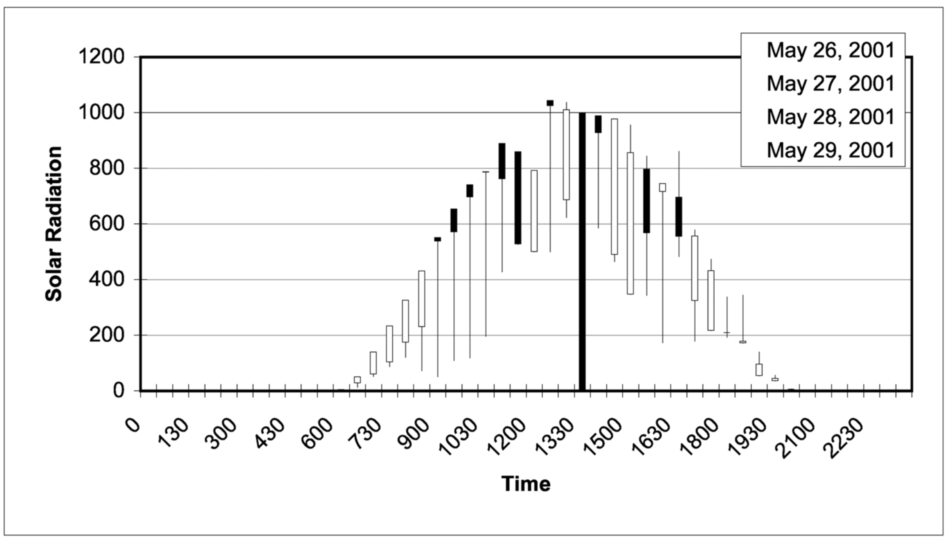
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Solar Radiation
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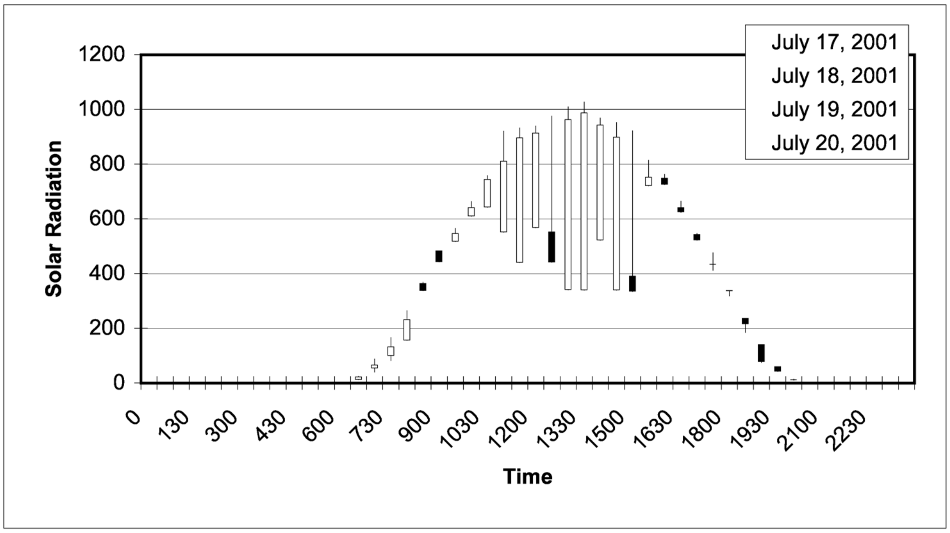

July 17, 2001
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July 19, 2001
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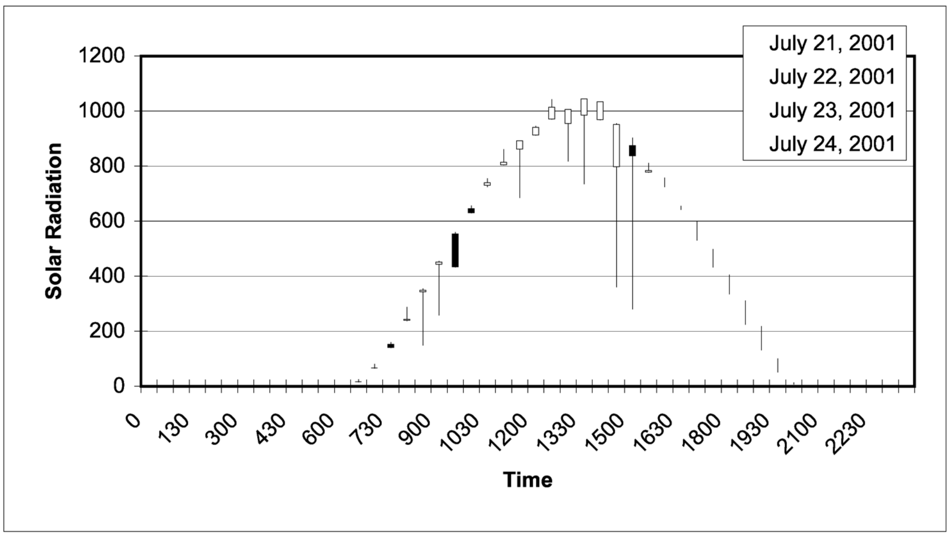
Time



July 21, 2001
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July 23, 2001
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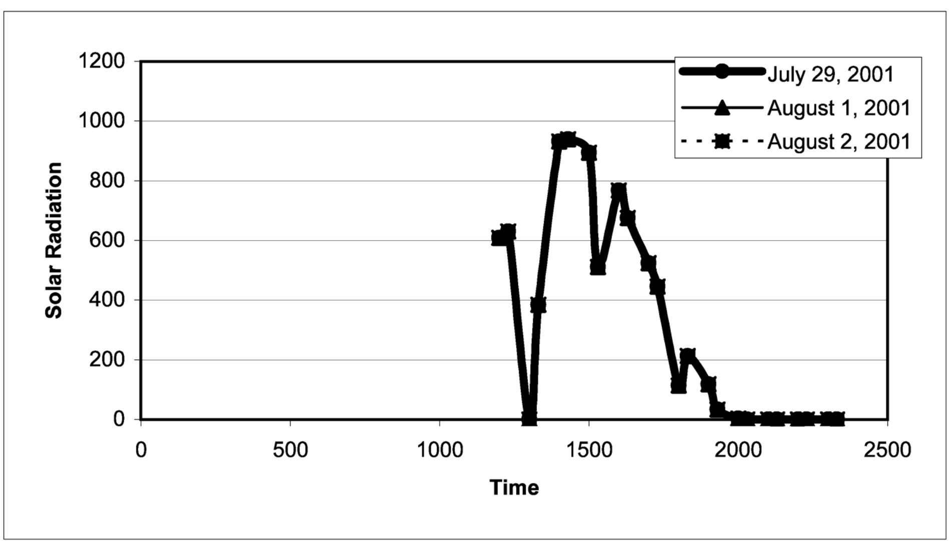
Time



July 29, 2001
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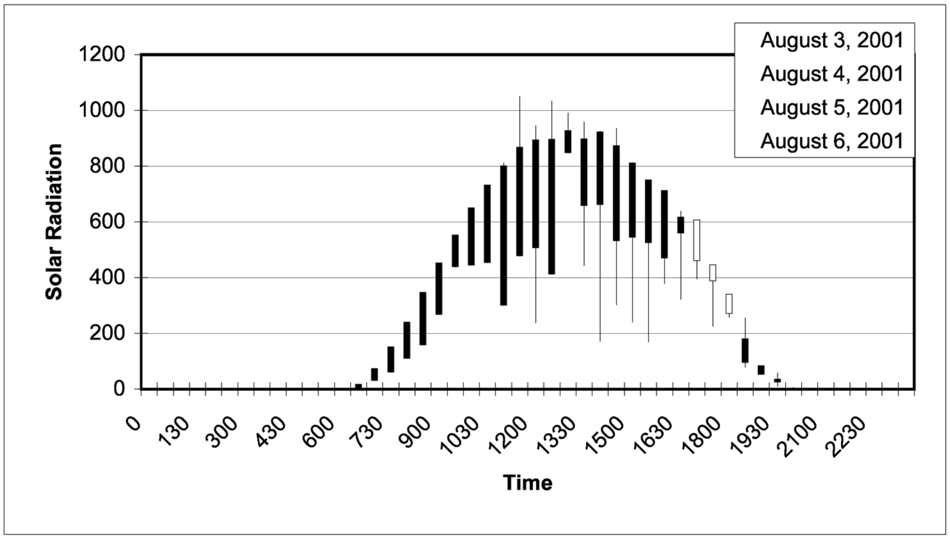
2000
2500
Time



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2100
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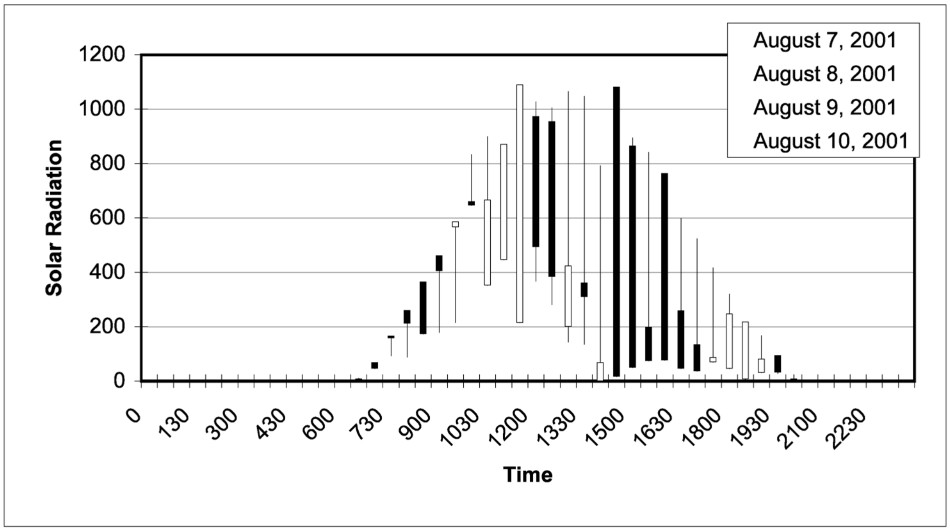
Time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Solar Radiation
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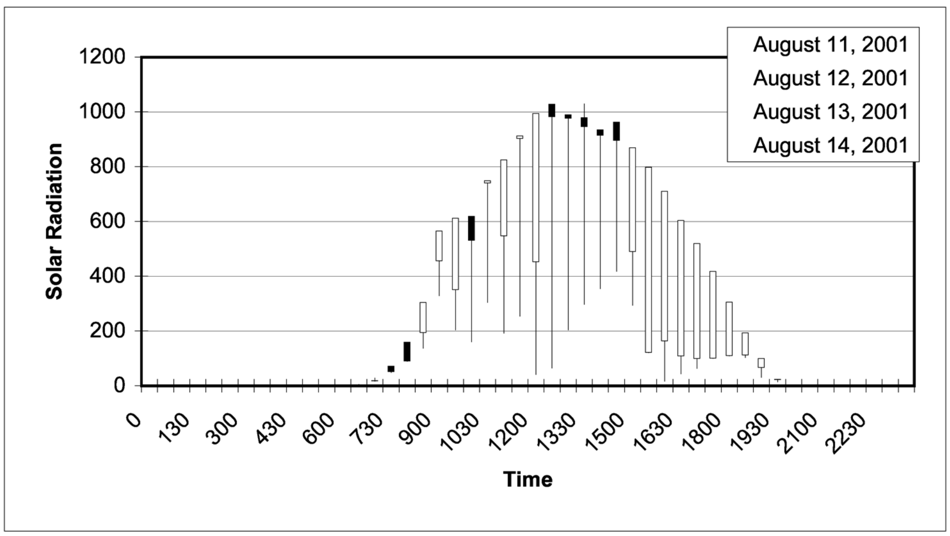
August 11, 2001
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August 13, 2001
August 14, 2001
Solar Radiation
Time
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400
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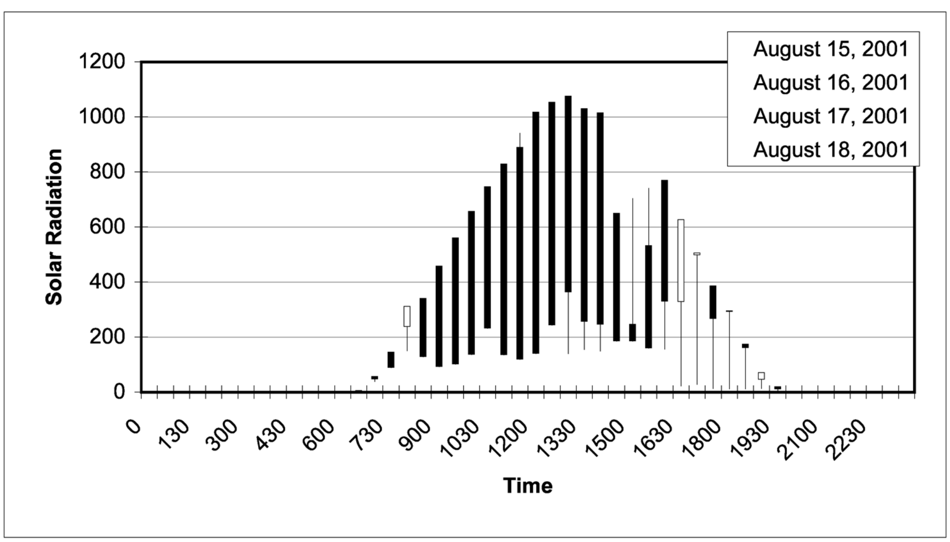
August 15, 2001
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Solar Radiation
Time
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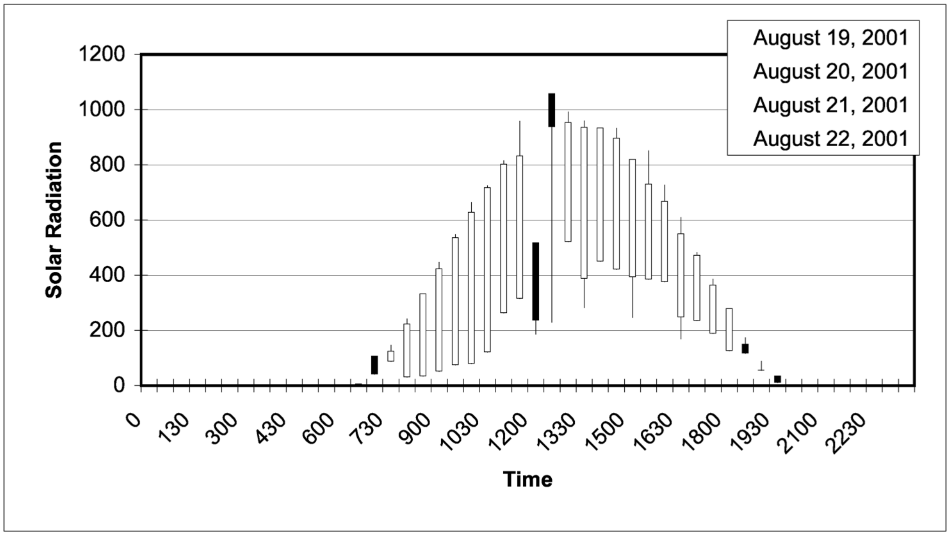

August 19, 2001
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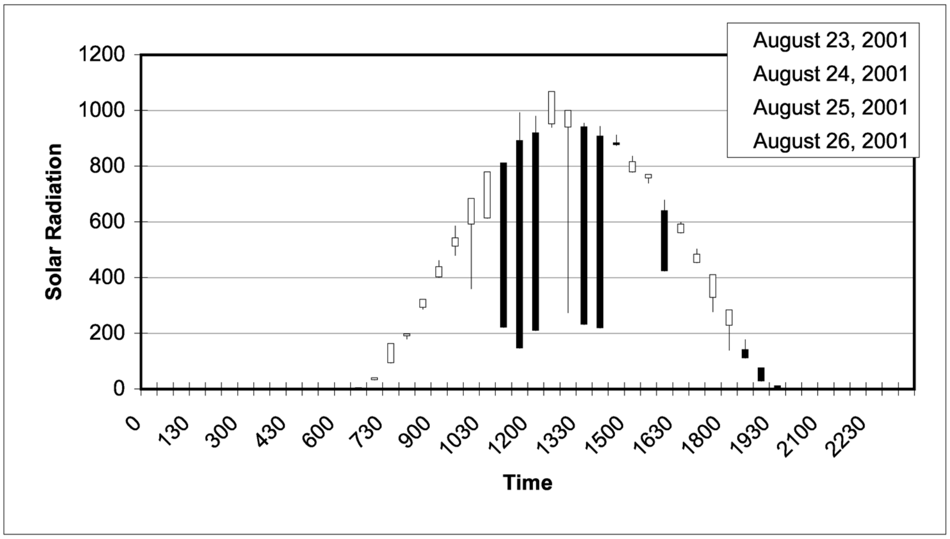
Time


August 23, 2001
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August 25, 2001
August 26, 2001
Solar Radiation
Time
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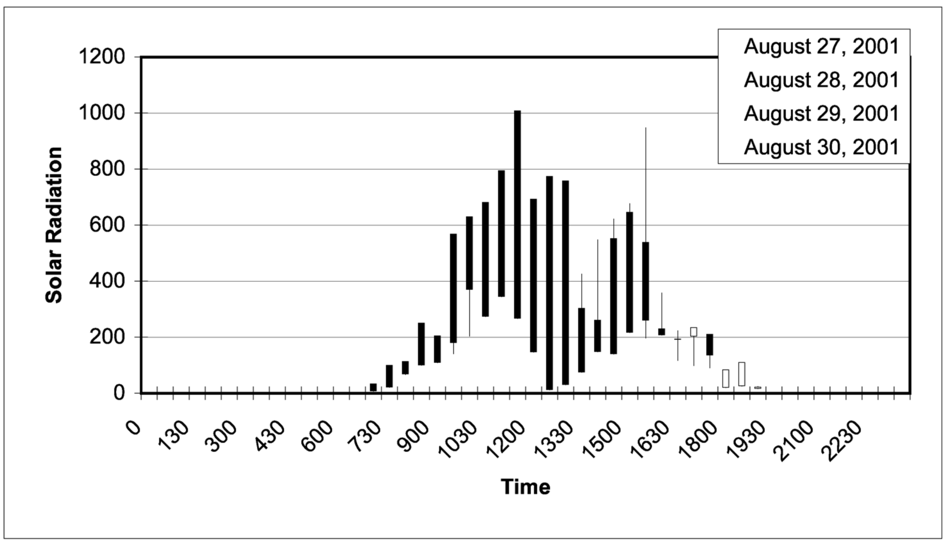
August 27, 2001
August 28, 2001
August 29, 2001
August 30, 2001
Solar Radiation
Time
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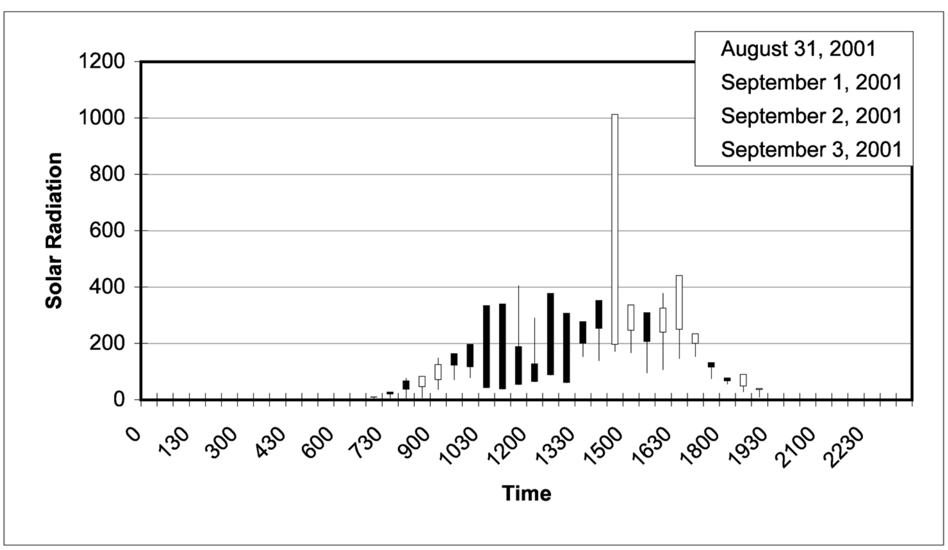
August 31, 2001
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September 2, 2001
September 3, 2001
Solar Radiation
Time
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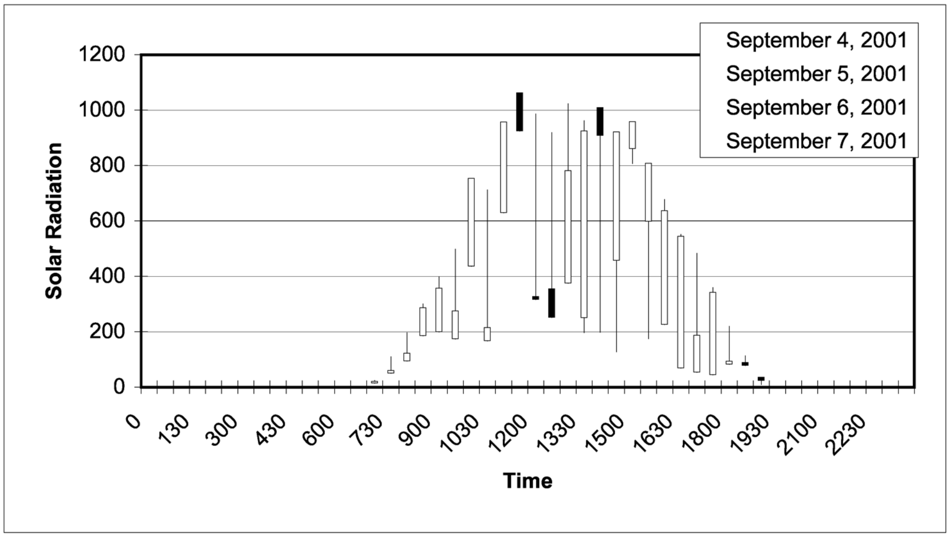
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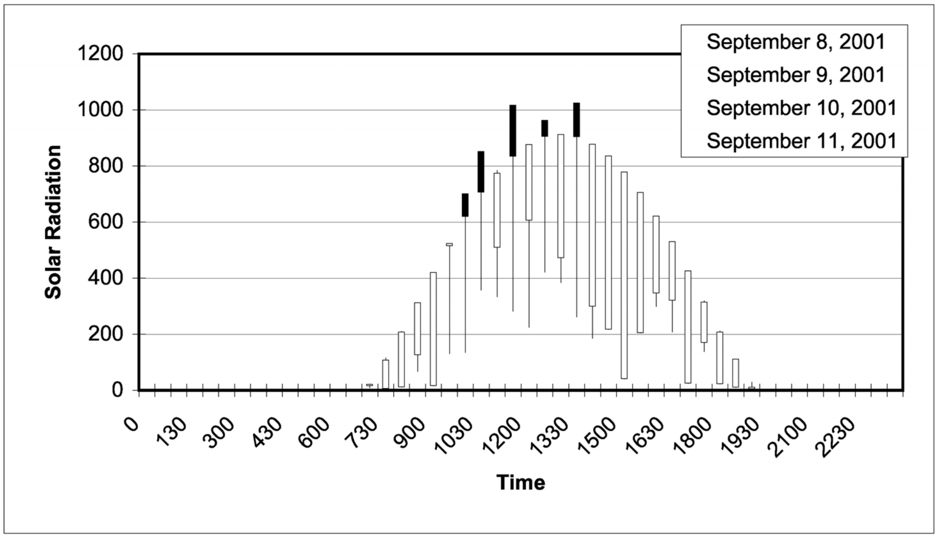
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Solar Radiation
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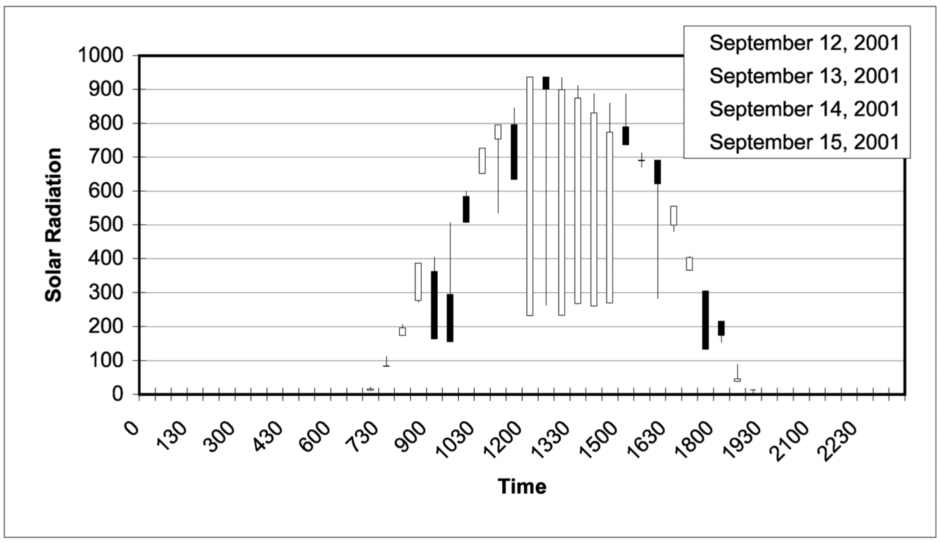
September 12, 2001
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Solar Radiation
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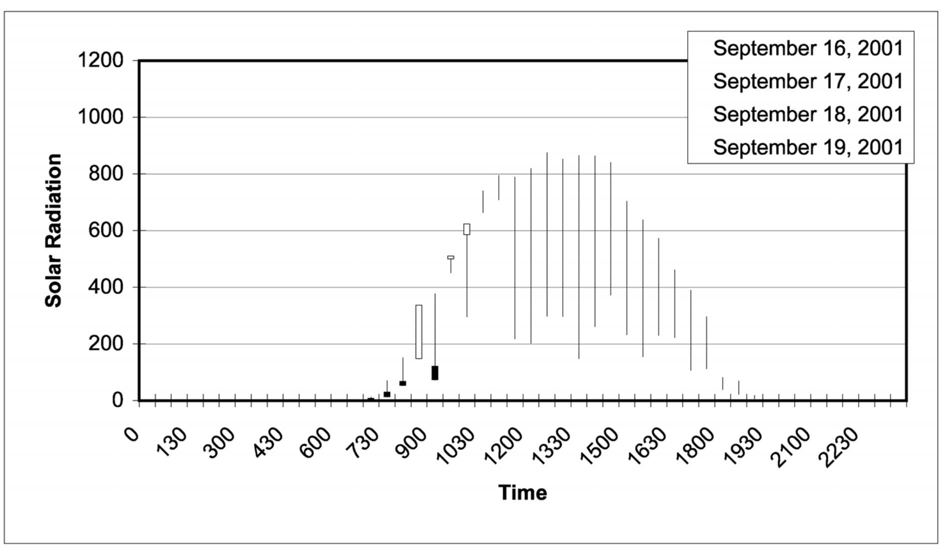
September 16, 2001
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Solar Radiation
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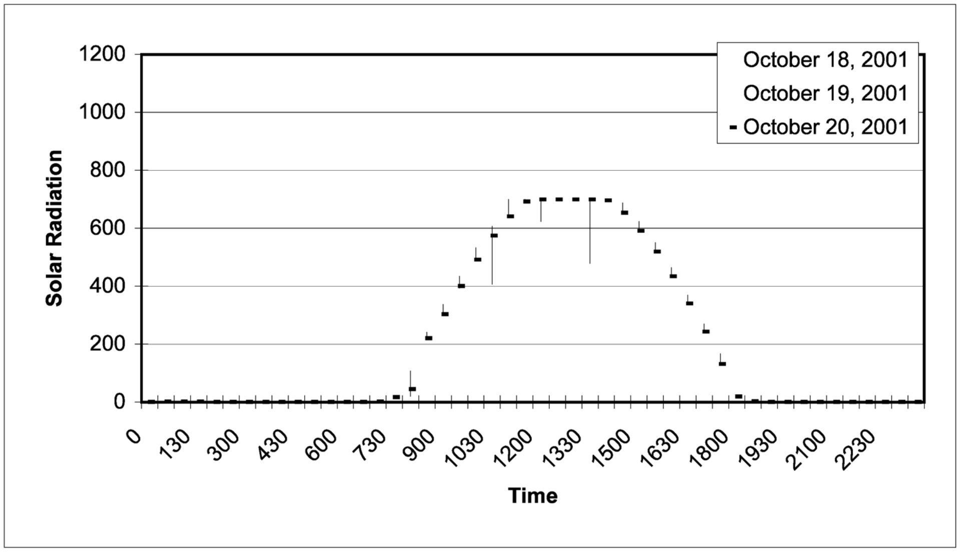

October 18, 2001
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Solar Radiation
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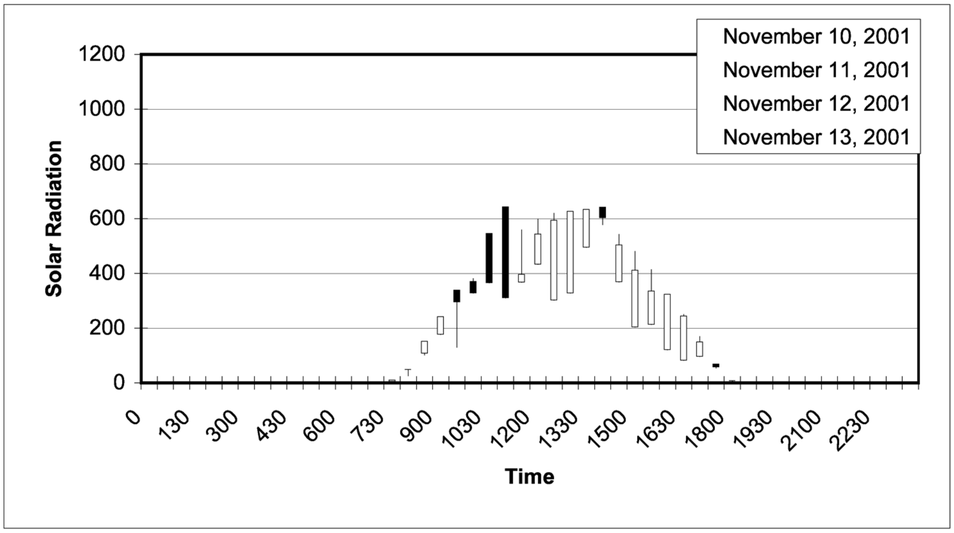
Time


November 10, 2001
November 11, 2001
November 12, 2001
November 13, 2001
Solar Radiation
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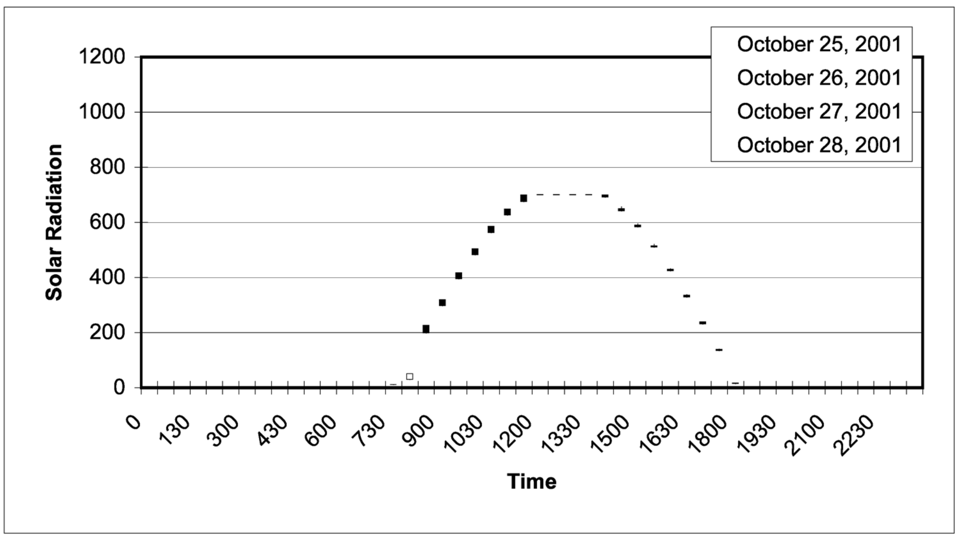
October 25, 2001
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October 28, 2001
Solar Radiation
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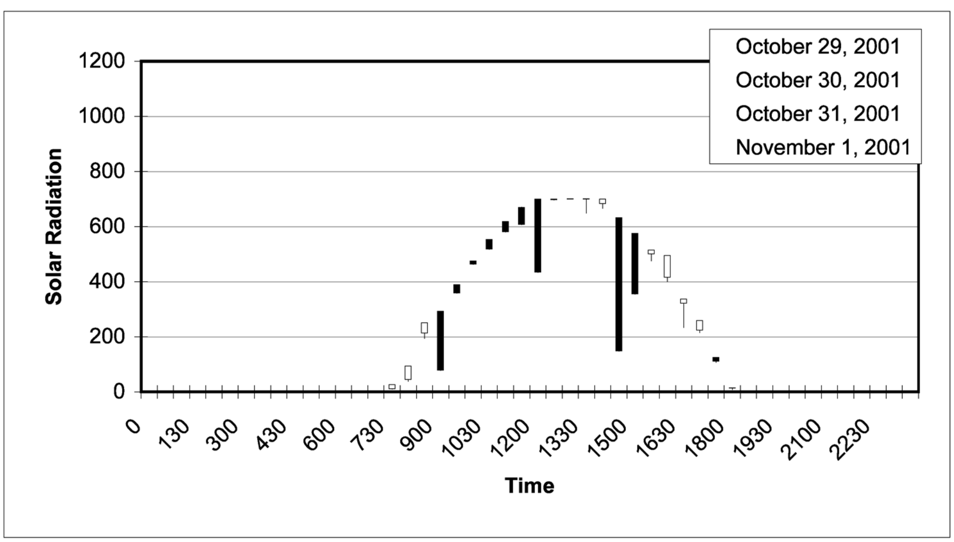
Time


October 29, 2001
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October 31, 2001
November 1, 2001
Solar Radiation
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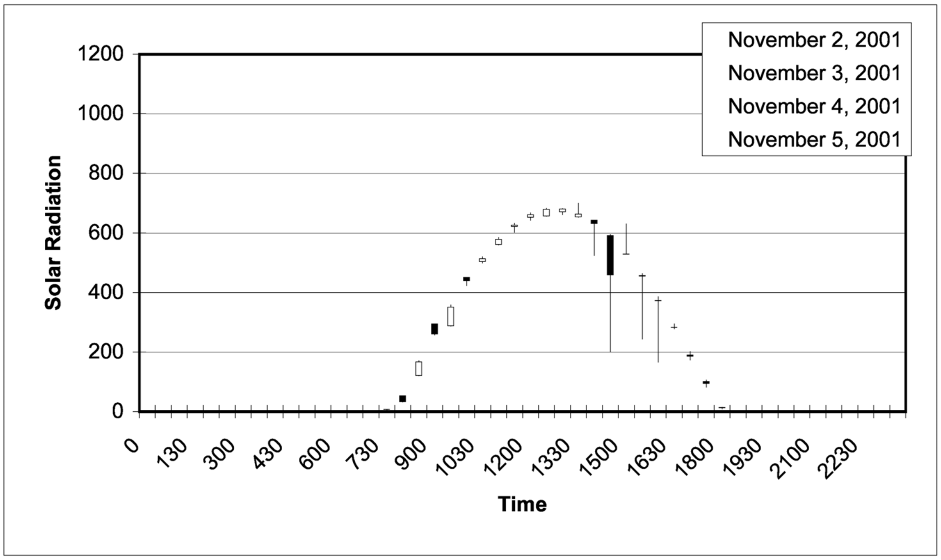
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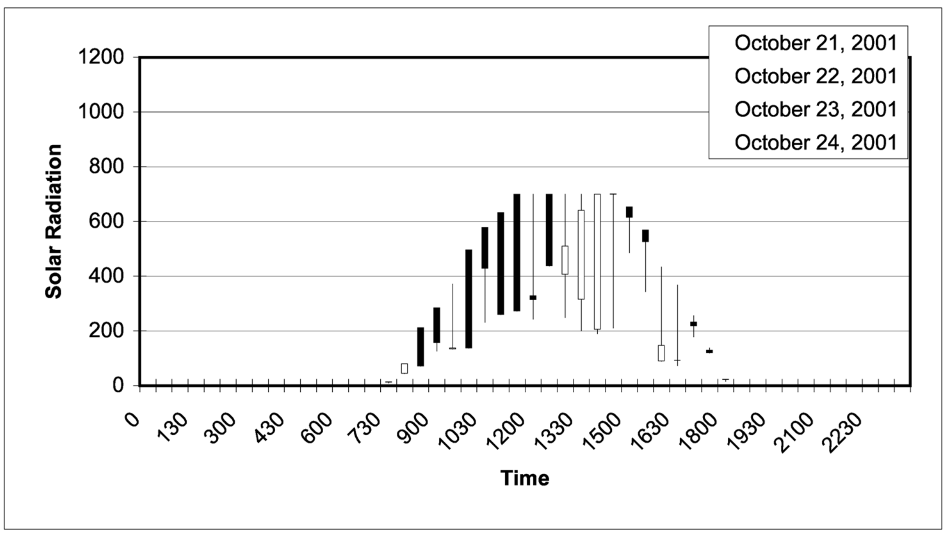
Time


October 21, 2001
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October 23, 2001
October 24, 2001
Solar Radiation
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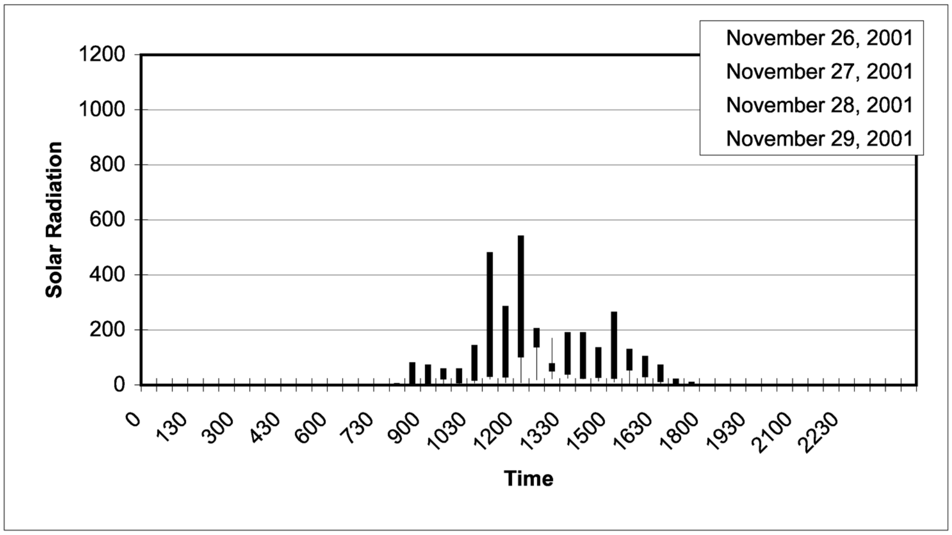
Time


November 26, 2001
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Solar Radiation
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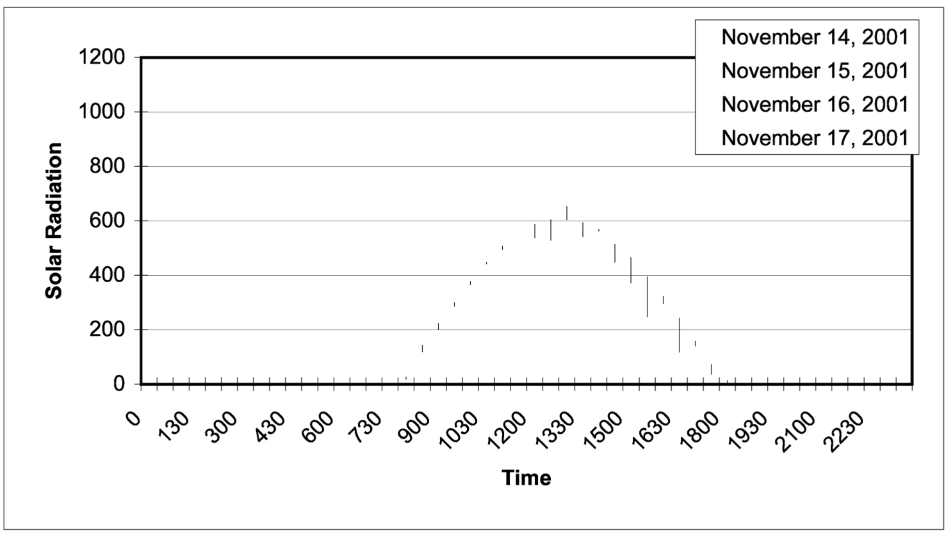
November 14, 2001
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November 17, 2001
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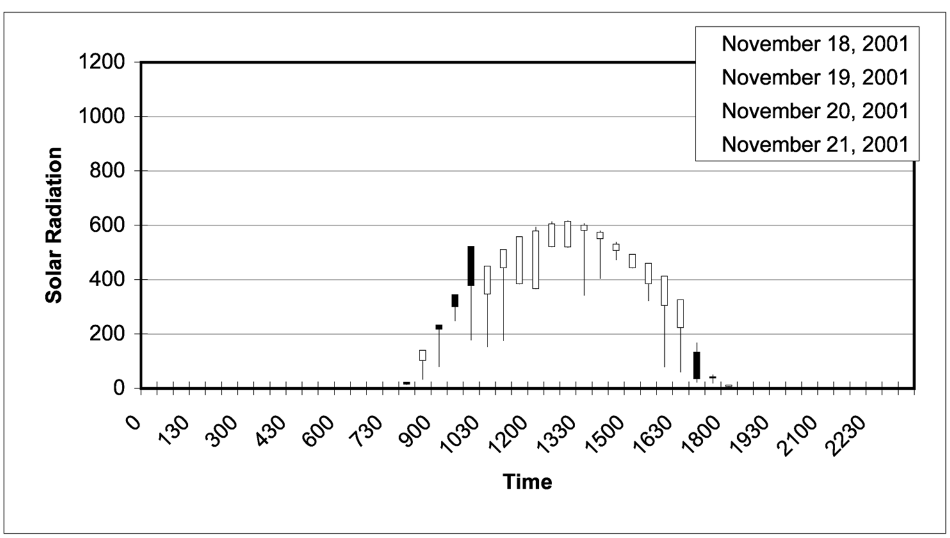
November 18, 2001
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November 21, 2001
Solar Radiation
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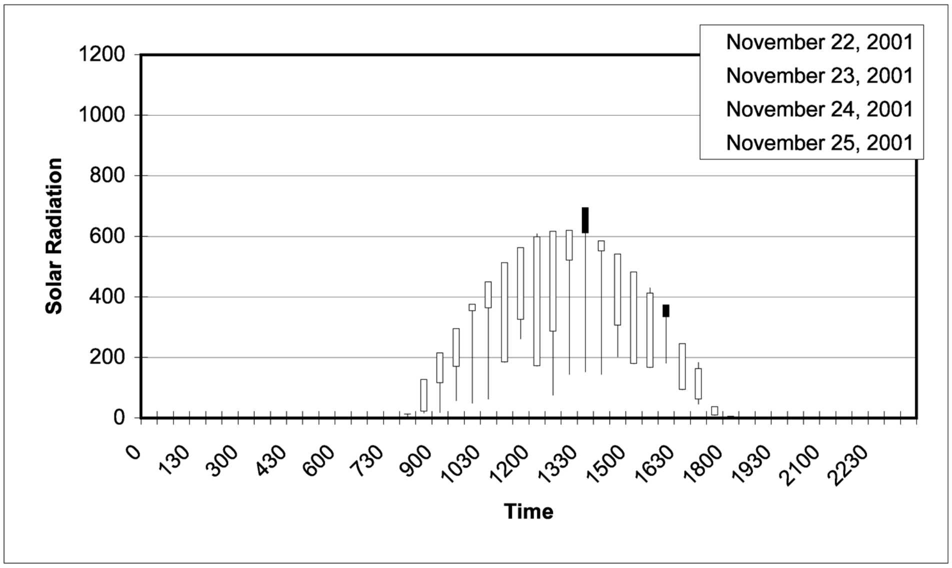
November 22, 2001
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November 24, 2001
November 25, 2001
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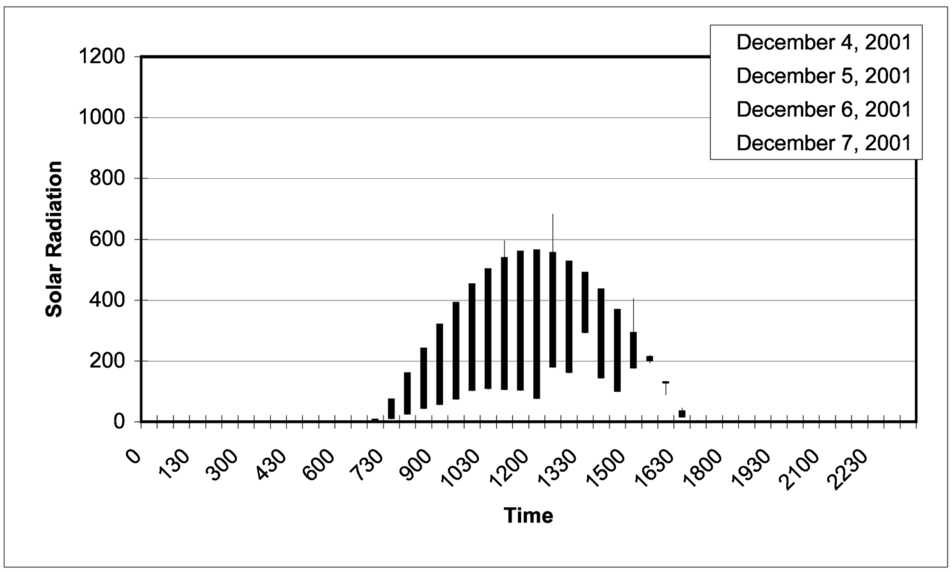
Time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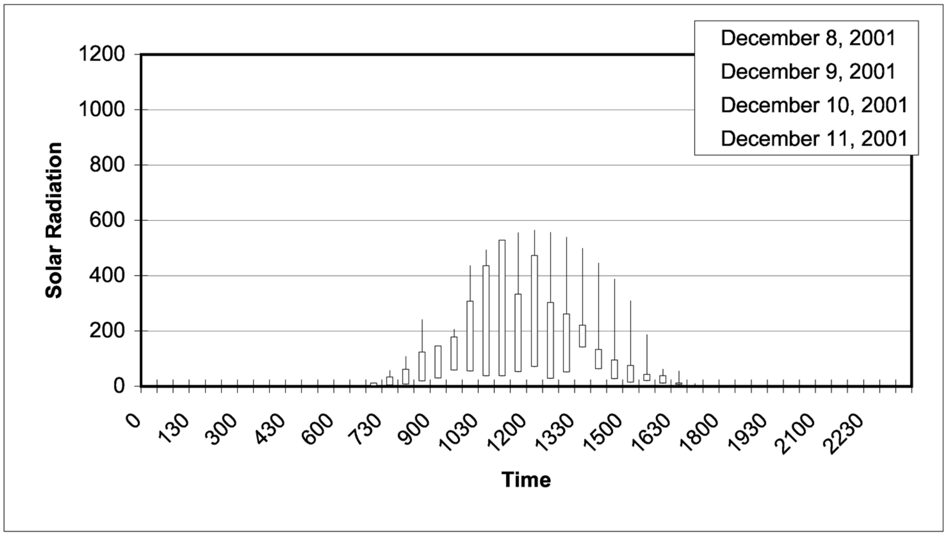
Time


December 8, 2001
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December 11, 2001
Solar Radiation
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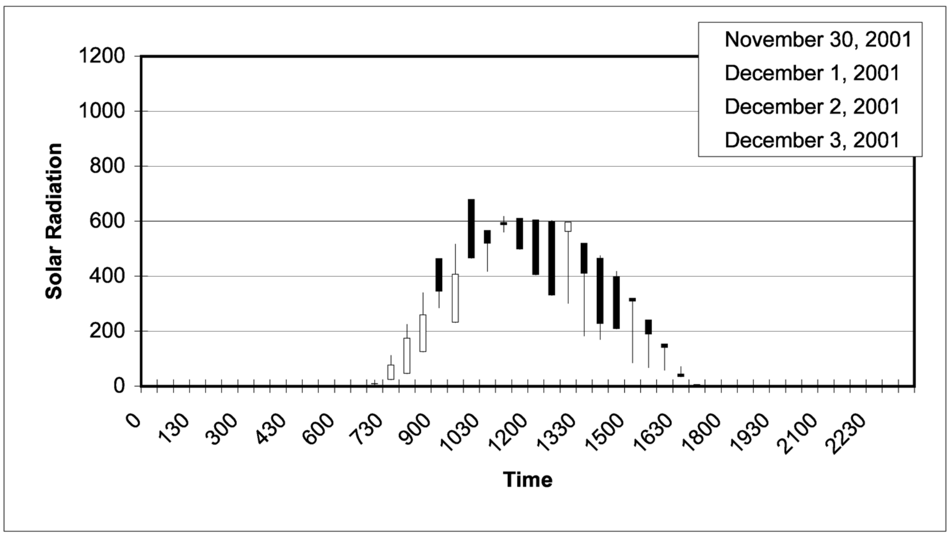
Time


November 30, 2001
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December 3, 2001
Solar Radiation
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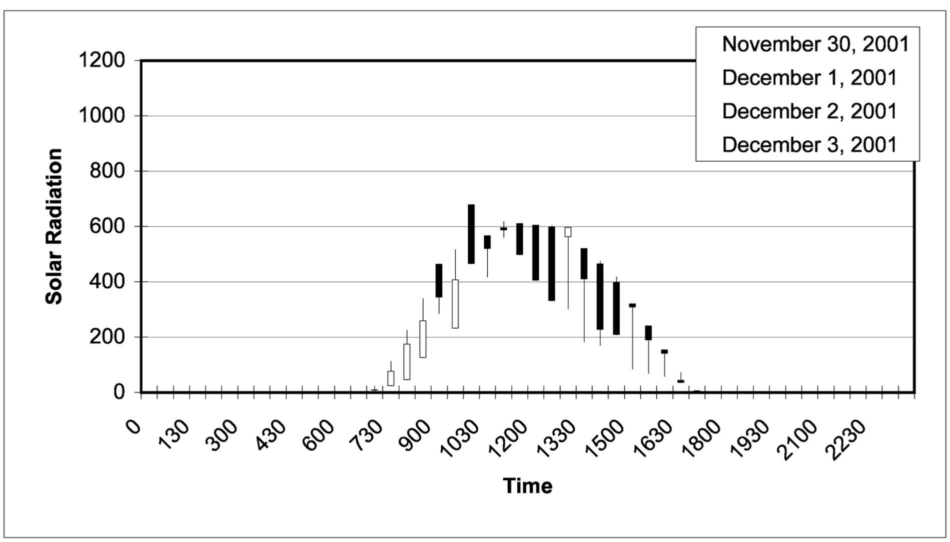
Time


November 30, 2001
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December 2, 2001
December 3, 2001
Solar Radiation
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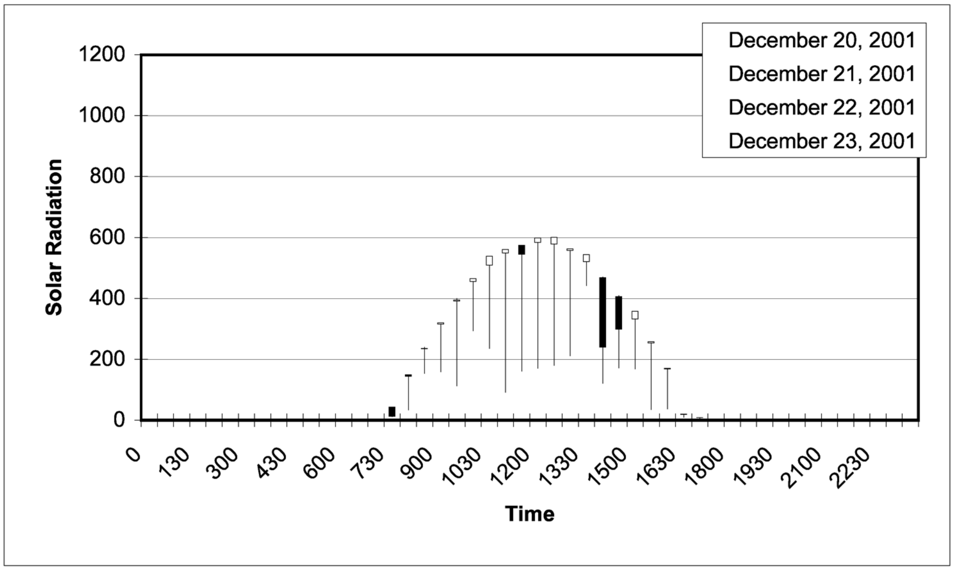
Time


December 20, 2001
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December 23, 2001
Solar Radiation
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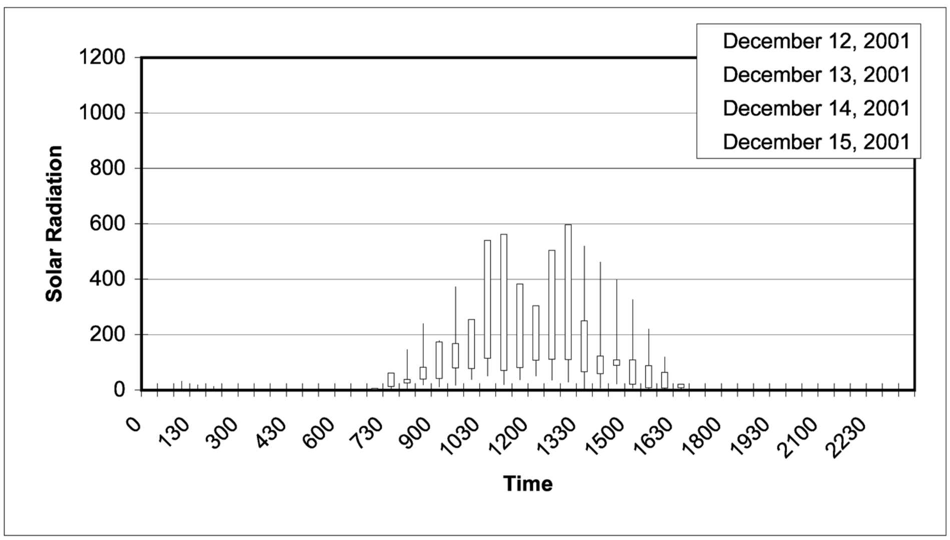
Time


December 12, 2001
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December 14, 2001
December 15, 2001
Solar Radiation
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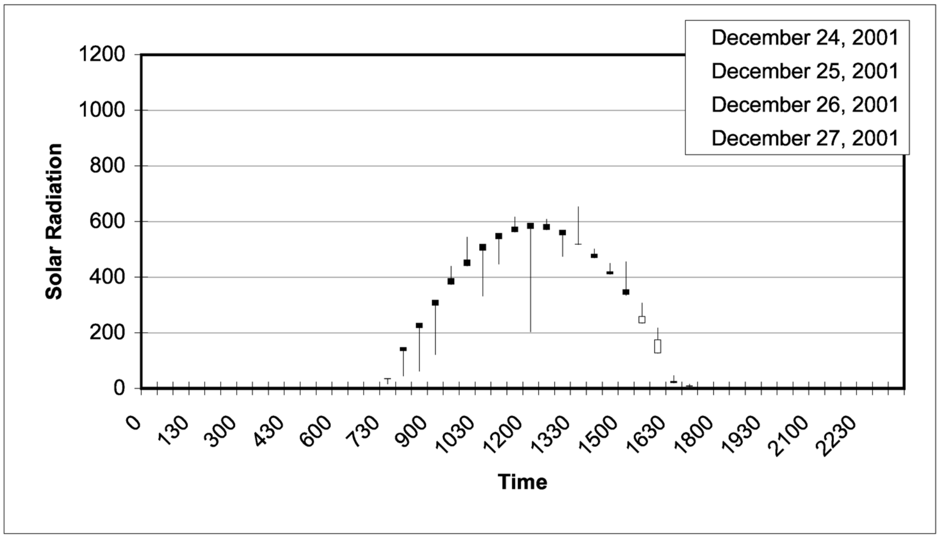
December 24, 2001
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December 27, 2001
Solar Radiation
Time
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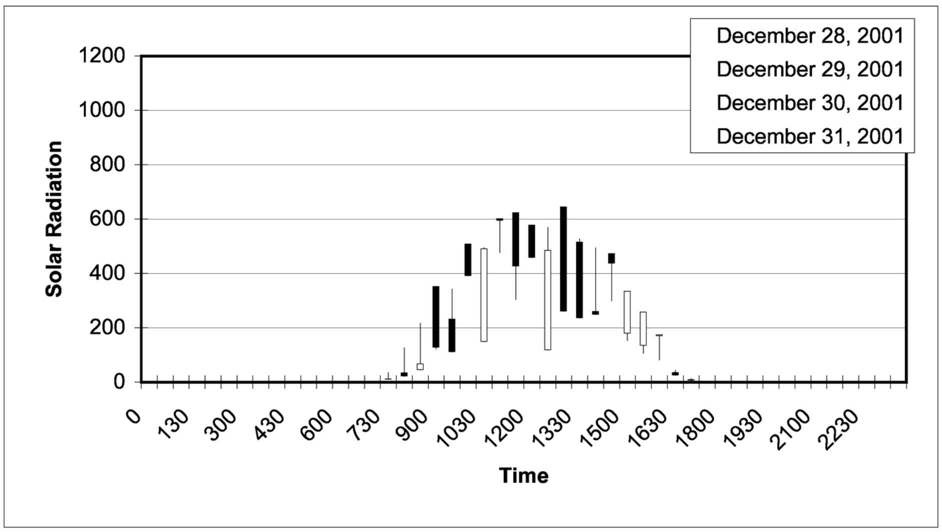
December 28, 2001
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December 31, 2001
Solar Radiation
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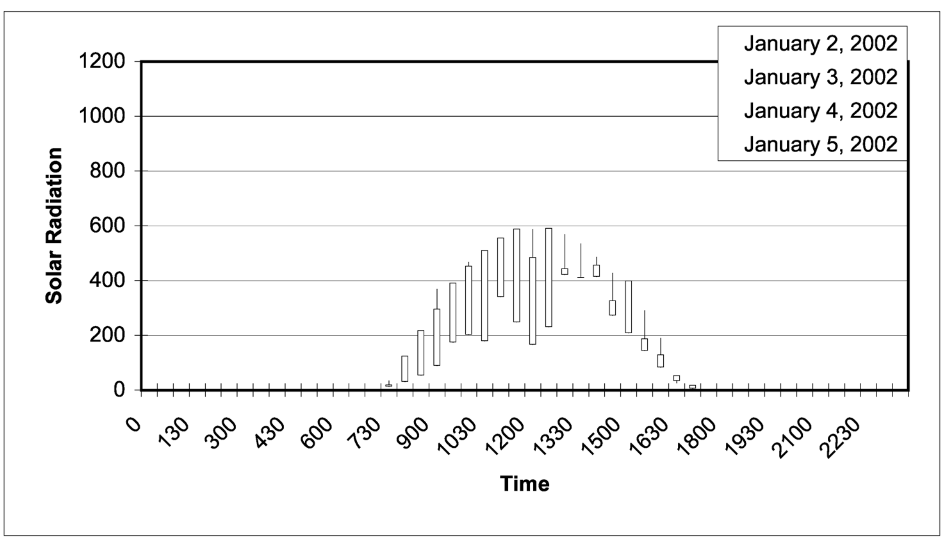
2230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January 4, 2002
January 5, 2002
Solar Radiation
Time
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600
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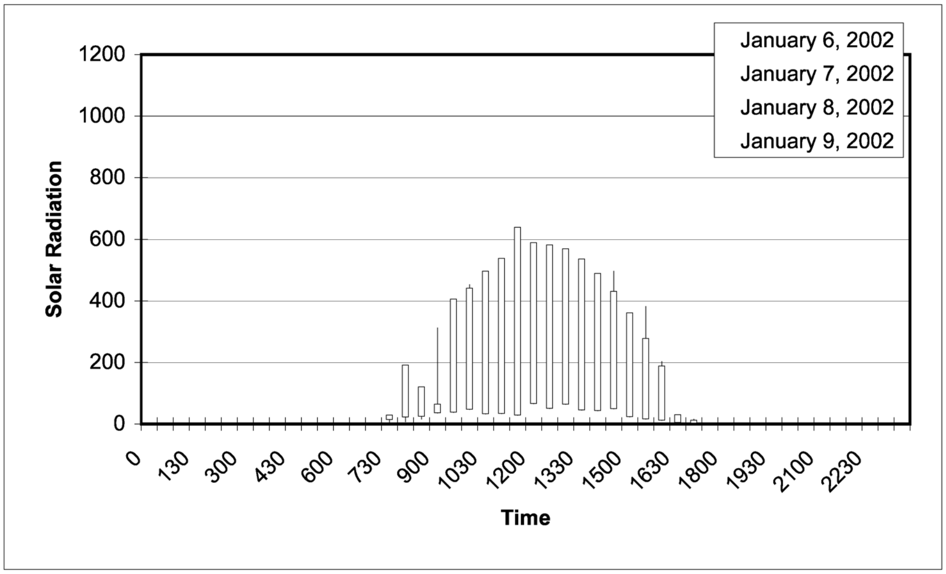
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230



January 6, 2002
January 7, 2002
January 8, 2002
January 9, 2002
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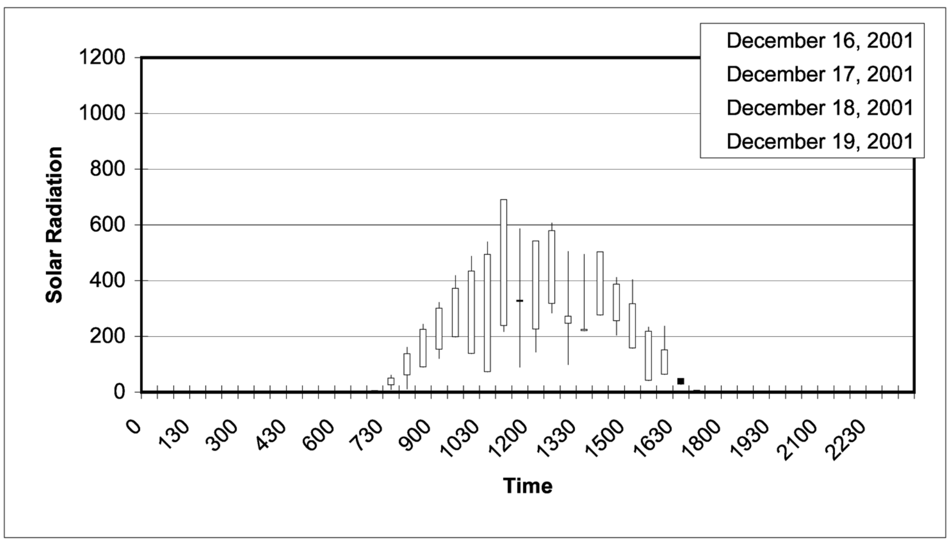
1500
1630
1800
1930
2100
2230
Time



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December 17, 2001
December 18, 2001
December 19, 2001
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800
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400
200
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Solar Radiation
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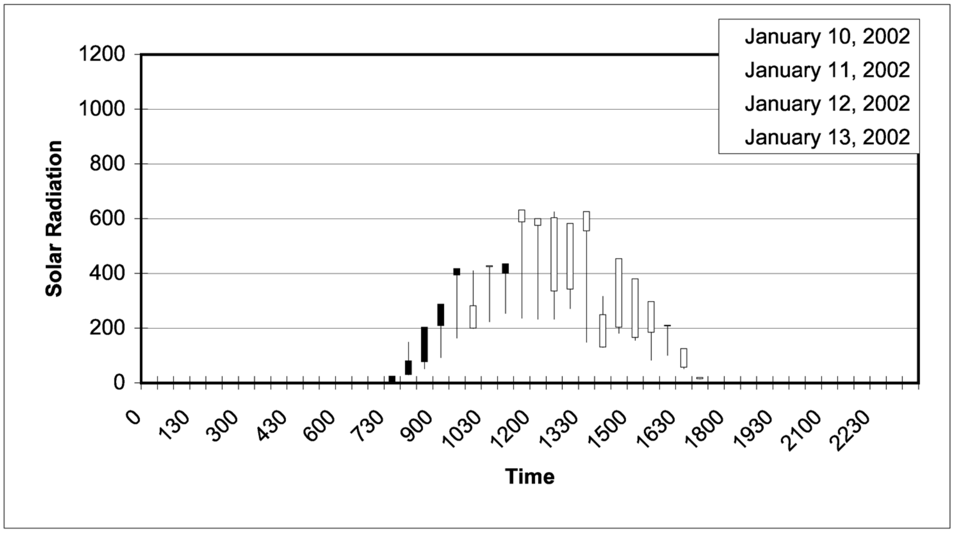
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time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January 12, 2002
January 13, 2002
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800
600
400
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0
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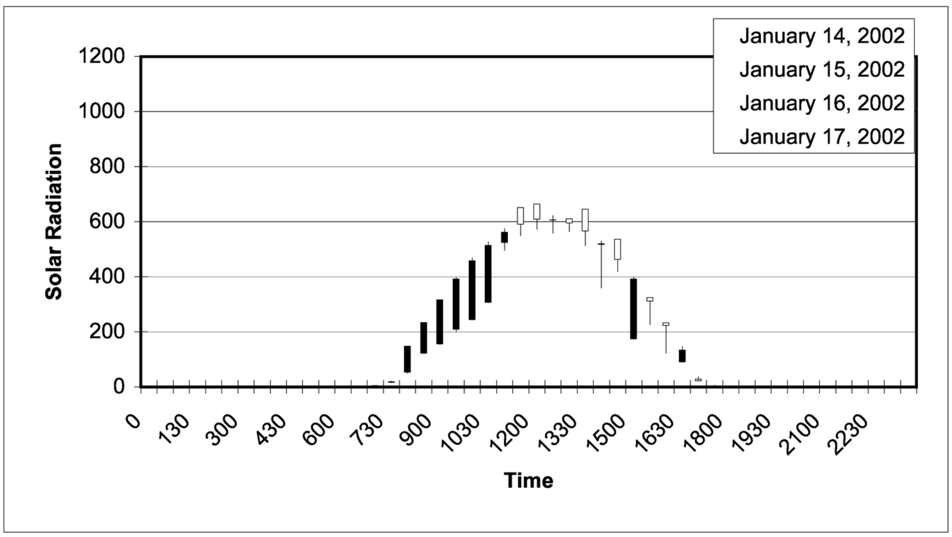
1500
1630
1800
1930
2100
2230
Time


January 14, 2002
January 15, 2002
January 16, 2002
January 17, 2002
Solar Radiation
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800
600
400
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1200
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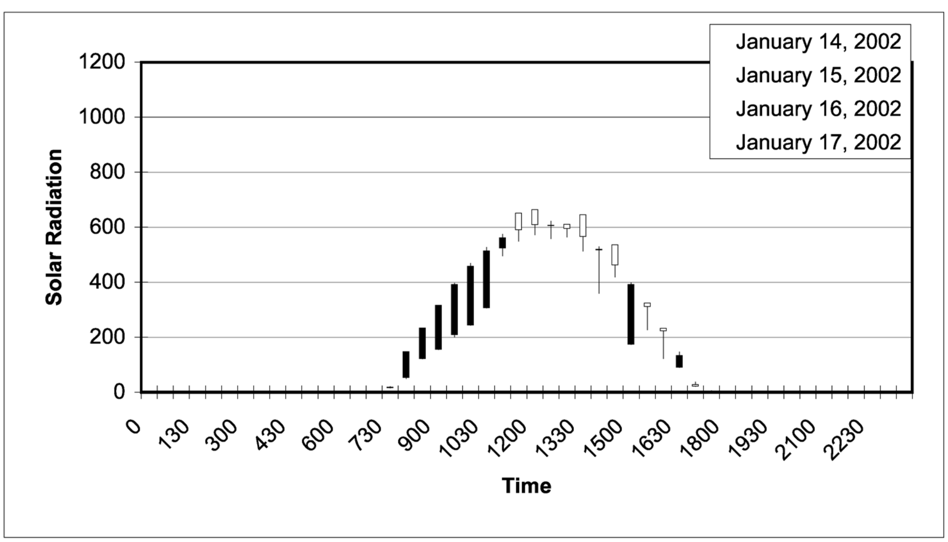
1800
1930
2100
2230
Time


January 14, 2002
January 15, 2002
January 16, 2002
January 17, 2002
Solar Radiation
1200
1000
800
600
400
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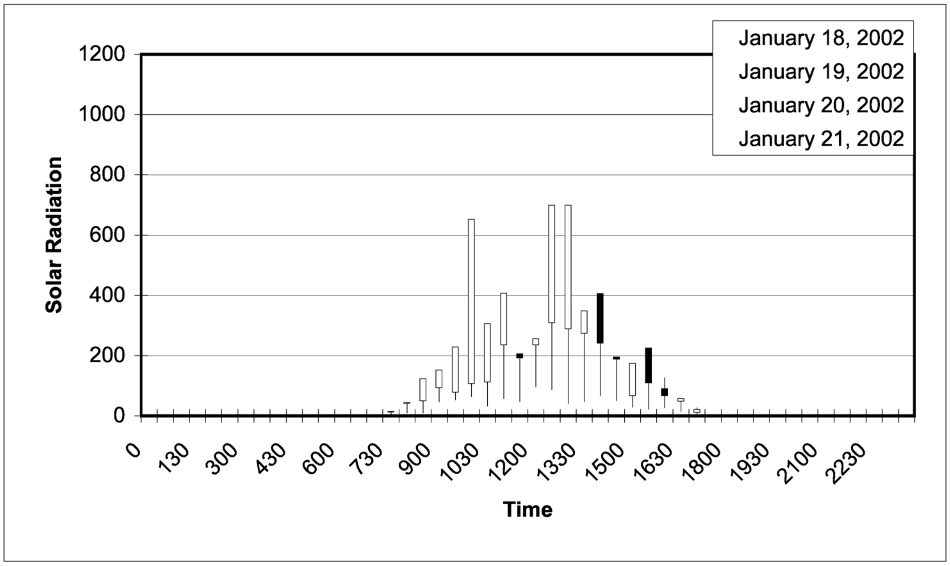
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time


January 18, 2002
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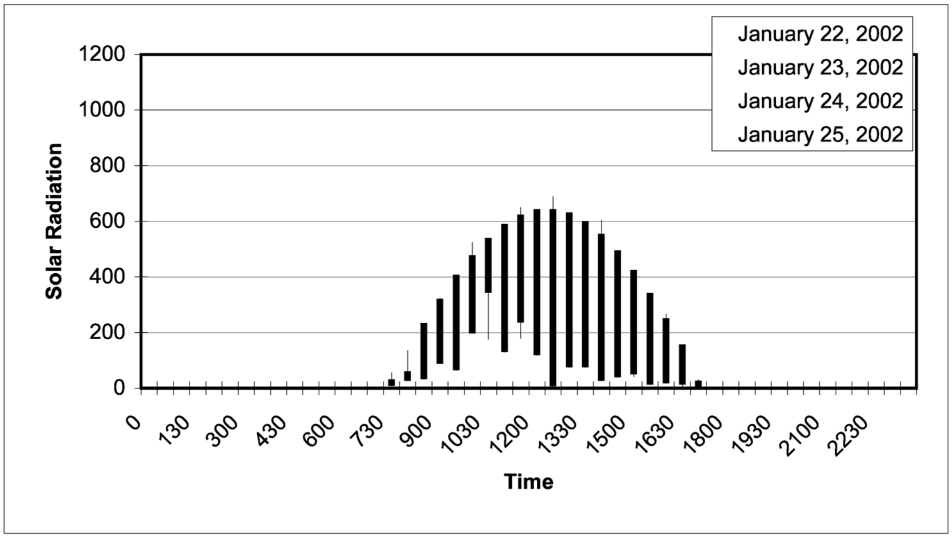
1800
1930
2100
2230
Time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January 23, 2002
January 24, 2002
January 25, 2002
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1000
800
600
400
200
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Solar Radiation
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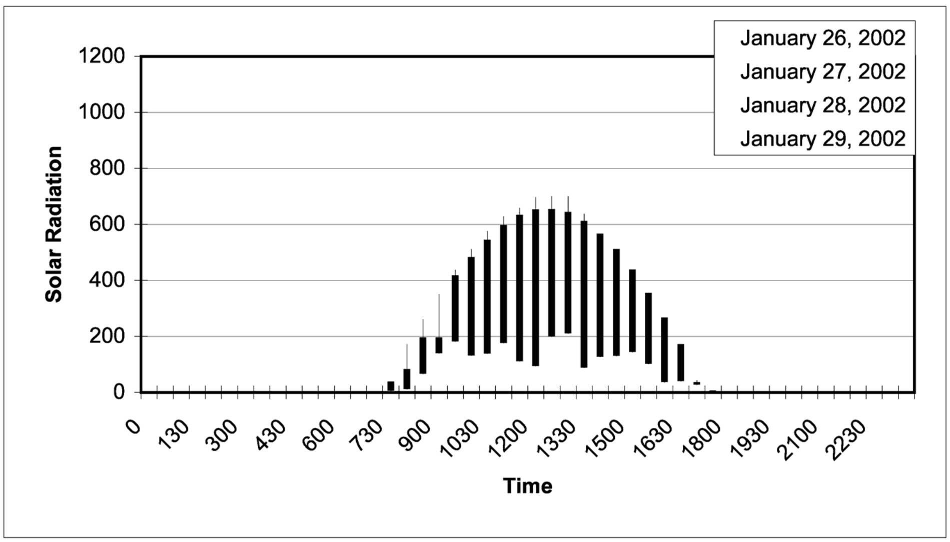
1800
1930
2100
2230
Time


January 26, 2002
January 27, 2002
January 28, 2002
January 29, 2002
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1000
800
600
400
200
0
Solar Radiation
0
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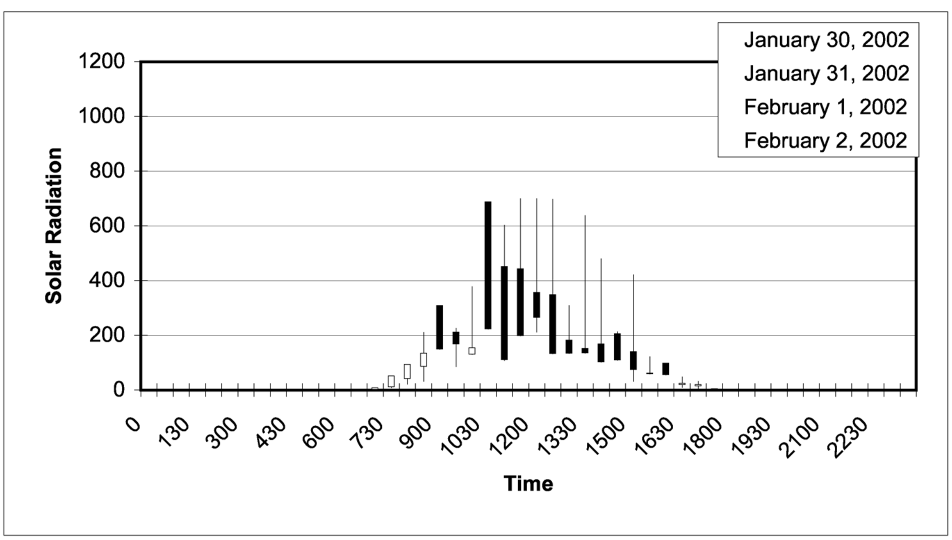
1800
1930
2100
2230
Time


January 30, 2002
January 31, 2002
February 1, 2002
February 2, 2002
1200
1000
800
600
400
200
0
Solar Radiation
0
130
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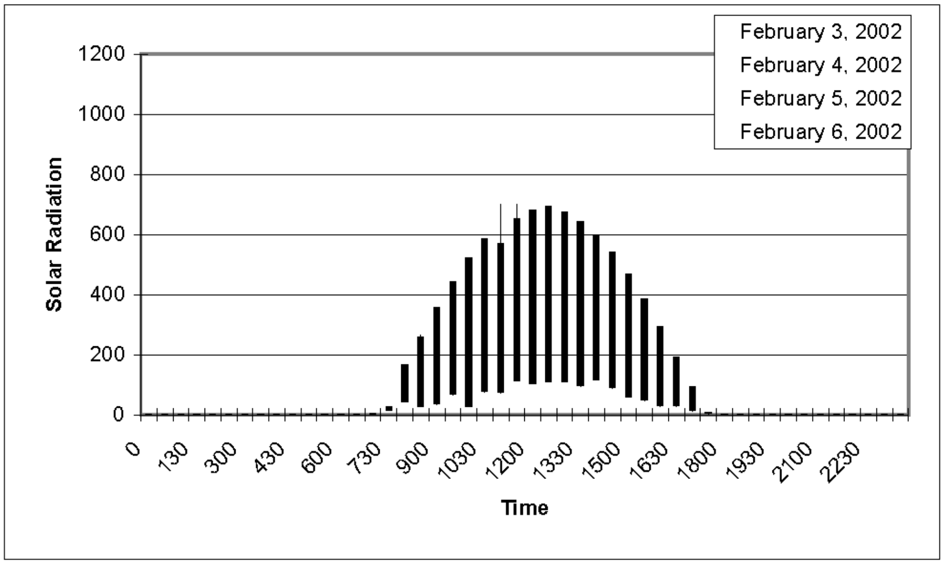
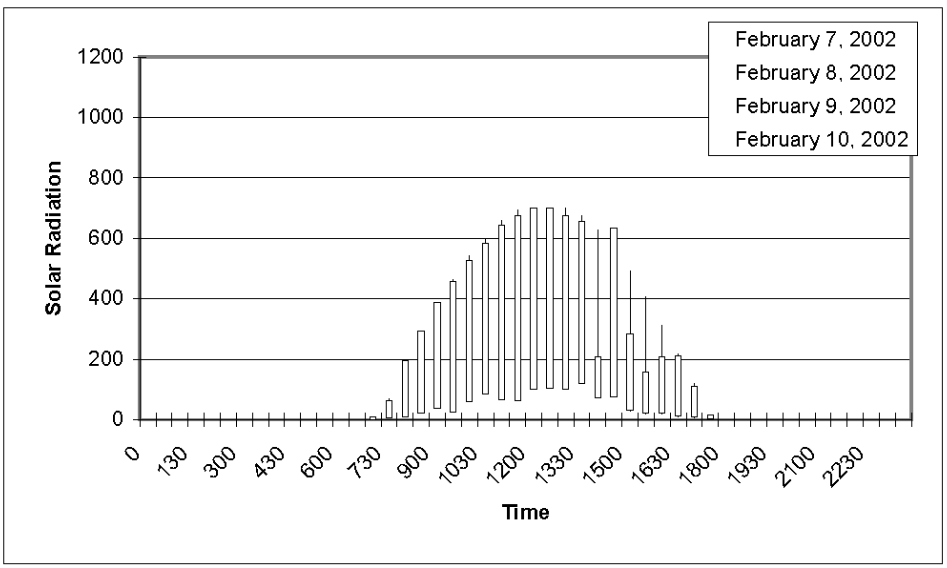
1800
1930
2100
2230
Time


February 3, 2002
February 4, 2002
February 5, 2002
February 6, 2002
Solar Radiation
1200
1000
800
600
400
200
0
0
130
300
430
600
730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time


February 7, 2002
February 8, 2002
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February 10, 2002
Solar Radiation
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730
900
1030
1200
1330
1500
1630
1800
1930
2100
2230
Time

Appendix E
Data from Permeability Tests

Tables E1 and E2 contain the permeameter data and the summary permeability values.

Table E1
Permeameter Data

Test 1A, Surface, 6/19/2002
Water Height in Well 5 CM

Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min	Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min
9:58	2	8.10			10:28	2	9.1		
10:00	2	10.10	2.0	1.00	10:30	2	10.6	1.5	0.75
10:02	2	11.50	1.4	0.70	10:32	2	12.0	1.4	0.70
10:04	2	12.50	1.0	0.50	10:34	2	13.5	1.5	0.75
10:06	2	12.80	0.3	0.15	10:36	2	15.0	1.5	0.75
10:08	2	14.20	1.4	0.70	10:38	2	16.4	1.4	0.70
10:10	2	15.70	1.5	0.75	10:40	2	17.7	1.3	0.65
10:12	2	17.20	1.5	0.75	10:42	2	19.1	1.4	0.70
10:14	2	18.60	1.4	0.70	10:44	2	20.8	1.7	0.85
10:16	2	20.10	1.5	0.75	10:46	2	22.2	1.4	0.70
10:18	2	21.50	1.4	0.70	10:48	2	23.7	1.5	0.75
10:20	2	22.90	1.4	0.70	10:50	2	25.2	1.5	0.75
10:22	2	24.70	1.8	0.90	10:52	2	26.7	1.5	0.75
10:24	2	25.90	1.2	0.60	10:54	2	28.4	1.7	0.85
10:26	2	27.10	1.2	0.60	10:56	2	29.7	1.3	0.65
Steady R1 0.65		Steady R2 0.74		Mean (R1) 0.011		Mean (R2) 0.012		Field Saturated Permeability -2.84E-04	

Test 1A, 6 inches, 6/19/2002
H1 Water Height in Cell 5 CM
H2 Water Height in Cell 10 CM

Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min	Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min
11:52	5	28.80			13:04	5	33.0		
11:57	5	29.20	0.4	0.08	13:09	5	32.9	-0.1	-0.02
12:02	5	29.20	0.0	0.00	13:14	5	33.4	0.5	0.10
12:07	5	29.50	0.3	0.06	13:19	5	33.8	0.4	0.08
12:12	5	29.80	0.3	0.06	13:24	5	34.7	0.9	0.18
12:17	5	30.60	0.8	0.16	13:29	5	34.6	-0.1	-0.02
12:22	5	30.90	0.3	0.06	13:34	5	35.1	0.5	0.10
12:27	5	30.90	0.0	0.00	13:39	5	35.7	0.6	0.12
12:32	5	31.00	0.1	0.02	13:44	5	35.7	0.0	0.00

(Sheet 1 of 4)

Table E1 (Continued)

Test 1A, 6 inches, 6/19/2002 (Continued)									
Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min	Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min
12:37	5	31.40	0.4	0.08	13:49	5	34.6	-1.1	-0.22
12:42	5	30.90	-0.5	-0.10	13:54	5	35.5	0.9	0.18
12:47	5	31.60	0.7	0.14	13:59	5	36.7	1.2	0.24
12:52	5	31.00	-0.6	-0.12	14:04	5	37.0	0.3	0.06
12:57	5	30.20	-0.8	-0.16	14:09	5	37.9	0.9	0.18
1:02	5	31.50	1.3	0.26	14:14	5	36.0	-1.9	-0.38
Steady R1 0.04		Steady R2 0.14		Mean (R1) 0.0007		Mean (R2) 0.0023		Field Saturated Permeability 1.93E-04	

Test 1A, 12 inches, 6/19/2002 H1 Water Height in Cell 5 CM H2 Water Height in Cell 10 CM									
Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min	Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min
9:35	5	15.50			13:18	5	21.0		
9:40	5	16.10	0.6	0.12	13:23	5	22.9	1.9	0.38
9:45	5	16.00	-0.1	-0.02	13:29	5	22.6	-0.3	-0.06
9:50	5	16.40	0.4	0.08	13:33	5	23.3	0.7	0.14
9:55	5	16.50	0.1	0.02	13:39	5	23.8	0.5	0.10
10:00	5	17.10	0.6	0.12	13:43	5	24.7	0.9	0.18
10:05	5	17.80	0.7	0.14	13:48	5	24.8	0.1	0.02
10:10	5	18.70	0.9	0.18	13:53	5	24.7	-0.1	-0.02
10:15	5	19.30	0.6	0.12	13:48	5	26.0	1.3	0.26
10:20	5	19.30	0.0	0.00	14:03	5	26.2	0.2	0.04
10:25	5	20.60	1.3	0.26	14:08	5	26.3	0.1	0.02
10:30	5	21.10	0.5	0.10	14:13	5	26.7	0.4	0.08
10:35	5	21.40	0.3	0.06	14:18	5	27.2	0.5	0.10
10:40	5	22.10	0.7	0.14	14:23	5	28.0	0.8	0.16
10:45	5	23.00	0.9	0.18	14:28	5	28.2	0.2	0.04
Steady R1 0.11		Steady R2 0.20		Mean (R1) 0.0019		Mean (R2) 0.0033		Field Saturated Permeability 1.18E-04	

(Sheet 2 of 4)

Table E1 (Continued)

Test 1B, Surface, 6/19/2002 H1 Water Height in Cell 5 CM H2 Water Height in Cell 10 CM									
Time	**Time Interval min**	**Water Level in Reservoir cm**	**Water Level Change cm**	**Rate of Water Level Change cm/min**	**Time**	**Time Interval min**	**Water Level in Reservoir cm**	**Water Level Change cm**	**Rate of Water Level Change cm/min**
11:51	2	4.80			12:20	2	7.8		
11:53	2	6.50	1.7	0.85	12:22	2	9.9	2.1	1.05
11:55	2	15.00	8.5	4.25	12:24	2	13.1	3.2	1.60
11:57	2	18.00	3.0	1.50	12:26	2	15.3	2.2	1.10
11:59	2	20.90	2.9	1.45	12:28	2	17.6	2.3	1.15
12:01	2	23.40	2.5	1.25	12:30	2	20.5	2.9	1.45
12:03	2	26.00	2.6	1.30	12:32	2	23.4	2.9	1.45
12:05	2	28.50	2.5	1.25	12:34	2	26.2	2.8	1.40
12:07	2	30.80	2.3	1.15	12:36	2	29.0	2.8	1.40
12:09	2	33.40	2.6	1.30	12:38	2	31.7	2.7	1.35
12:11	2	35.70	2.3	1.15	12:40	2	35.8	4.1	2.05
12:13	2	41.00	5.3	2.65	12:42	2	38.0	2.2	1.10
12:15	2	43.30	2.3	1.15	12:44	2	39.8	1.8	0.90
12:17	2	45.60	2.3	1.15	12:46	2	42.5	2.7	1.35
12:19	2	48.00	2.4	1.20	12:48	2	45.3	2.8	1.40
Steady R1 1.29		Steady R2 1.38		Mean (R1) 0.0216		Mean (R2) 0.0230		Field Saturated Permeability -7.80E-04	
Test 1B, 6 inches, 6/19/2002 H1 Water Height in Cell 5 CM H2 Water Height in Cell 10 CM									
Time	**Time Interval min**	**Water Level in Reservoir cm**	**Water Level Change cm**	**Rate of Water Level Change cm/min**	**Time**	**Time Interval min**	**Water Level in Reservoir cm**	**Water Level Change cm**	**Rate of Water Level Change cm/min**
12:18	5	29.50			13:30	5	33.5		
12:23	5	30.50	1.0	0.20	13:35	5	37.1	3.6	0.72
12:29	5	31.40	0.9	0.18	13:40	5	39.9	2.8	0.56
12:33	5	32.60	1.2	0.24	13:45	5	42.5	2.6	0.52
12:38	5	33.30	0.7	0.14	13:50	5	44.5	2.0	0.40

(Sheet 3 of 4)

Table E1 (Continued)

Test 1B, 6 inches, 6/19/2002 (Continued)

Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min	Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min
12:43	5	34.30	1.0	0.20	13:55	5	46.5	2.0	0.40
12:48	5	34.80	0.5	0.10	14:00	5	48.2	1.7	0.34
12:53	5	35.80	1.0	0.20	14:02	2	48.9	0.7	0.35
12:58	5	36.70	0.9	0.18	14:04	2	49.7	0.8	0.40
13:03	5	37.40	0.7	0.14	14:06	2	50.2	0.5	0.25
13:08	5	38.50	1.1	0.22	14:08	2	51.2	1.0	0.50
13:13	5	38.70	0.2	0.04	14:10	2	51.9	0.7	0.35
13:18	5	39.10	0.4	0.08	14:12	2	52.4	0.5	0.25
13:23	5	40.10	1.0	0.20	14:14	2	53.2	0.8	0.40
13:28	5	40.40	0.3	0.06	14:16	2	53.8	0.6	0.30
Steady R1 0.18		Steady R2 0.37		Mean (R1) 0.0030		Mean (R2) 0.0062		Field Saturated Permeability 3.30E-04	

Test 1B, 12 inches, 6/19/2002
H1 Water Height in Cell 5 CM
H2 Water Height in Cell 10 CM

Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min	Time	Time Interval min	Water Level in Reservoir cm	Water Level Change cm	Rate of Water Level Change cm/min
9:39	5	20.00			11:34	5	23.0		
9:44	5	19.90	-0.1	-0.02	11:39	5	31.0	8.0	1.60
9:49	5	19.80	-0.1	-0.02	11:41	2	33.3	2.3	1.15
9:54	5	20.10	0.3	0.06	11:43	2	35.5	2.2	1.10
9:59	5	20.50	0.4	0.08	11:45	2	37.5	2.0	1.00
10:04	5	21.90	1.4	0.28	11:47	2	39.5	2.0	1.00
10:09	5	21.50	-0.4	-0.08	11:49	2	41.0	1.5	0.75
10:14	5	22.10	0.6	0.12	11:51	2	43.8	2.8	1.40
10:19	5	22.00	-0.1	-0.02	11:54	2	45.7	1.9	0.95
10:24	5	22.70	0.7	0.14	11:55	2	47.4	1.7	0.85
10:29	5	23.40	0.7	0.14	11:57	2	49.5	2.1	1.05
10:34	5	24.10	0.7	0.14	11:59	2	52.2	2.7	1.35
10:39	5	23.90	-0.2	-0.04	12:01	2	54.2	2.0	1.00
11:34	5	23.70	-0.2	-0.04	12:03	2	56.0	1.8	0.90
11:39	5	23.80	0.1	0.02	12:05	2	58.0	2.0	1.00
Steady R1 0.14		Steady R2 1.03		Mean (R1) 0.0023		Mean (R2) 0.0172		Field Saturated Permeability 2.03E-03	

(Sheet 4 of 4)

Table E2
Summary of Permeability Values

	Field Saturated Permeability
Surface	**N/A**
0-6	2.61E-04
6-12	1.07E-03
Average	6.67E-04

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A CD containing data calibration and analysis spreadsheets is included with the printed version of this report.

14. ABSTRACT

This report provides data from a weather station near Mound, LA, on a fluvial plain at a site entitled Mud Lake. Mud Lake is located across the Mississippi River, 10 miles from Vicksburg, MS. The weather station data were collected over a 1-year period. These data are reported real-time through telemetry to the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg. Data collection teams were sent to the site intermittently to collect soil moisture, soil strength, and other related soils data for calibration with the weather station probes and support of input requirements to FASSST-C.

15. SUBJECT TERMS

Moisture	Validation data
Soil model	Weather station

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